SEQUESTRATION AND DYNAMICS OF CARBON AND NITROGEN IN SOILS OF DISSIMILAR LITHOLOGIES UNDER DIFFERENT LAND USE TYPES IN SOUTHEASTERN NIGERIA

BY

AHUKAEMERE, CHIOMA MILDRED (B. Agric, M.Sc.)
Reg. No. 20094735268

A THESIS SUBMITTED TO POSTGRADUATE SCHOOL
FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI.

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTORATE DEGREE (Ph.D) IN THE DEPARTMENT OF SOIL SCIENCE AND TECHNOLOGY, (SOIL SURVEY AND LAND USE PLANNING)

June, 2015.

CERTIFICATION

This is to certify that this research work “Sequestration and Dynamics of Carbon and Nitrogen in Soils of Dissimilar Lithologies Under Different Land Use Types in South-eastern Nigeria” was carried out by **Ahukaemere**, **Chioma Mildred** (**Reg. No. 20094735268**) as Ph. D thesis in the Department of Soil Science and Technology, School of Agriculture and Agricultural Technology, Federal University of Technology, Owerri.

---------------------------------	-------------------------------
Prof. F.O.R. Akamigbo (Project Supervisor)	Date
-----------------------------------	----------------------------------
Dr. E.U. Onweremadu (Co-Project Supervisor)	Date
-----------------------------------	----------------------------------
Dr. E.U. Onweremadu (Ag. Head of Department, SST)	Date
-----------------------------------	-----------------------------------
Prof. J. S. Orebiyi (Dean, SAAT)	Date
-----------------------------------	------------------------------------
Engr. (Prof.) K.B. Oyoh (Dean, Post Graduate School)	Date
-----------------------------------	-----------------------------------
External examiner	Date

DEDICATION

This work is dedicated to God Almighty and my family

ACKNOWLEDGEMENTS

My utmost gratitude goes to God Almighty whose immense protection, guidance, inspiration and grace became indispensable in the course of the execution of this research work.

I wish to express my profound and humble appreciation to my project supervisor, Prof. F.O.R. Akamigbo and co-supervisor, Dr. E.U. Onweremadu under whose constructive criticism and mentorship this work was completed.

I thank in a special way Prof. G.E. Osuji, Prof. E.T Eshett and Prof. N.N Oti under whose mentorship and tutelage this research work was carried out. Indeed, their versatility in the field of Soil Science gave the much needed attention and expertise in the prosecution of this work.

Others who gave practical meaning to this work are Mr. Olufemi – the laboratory Technologist in the Department of Soil Science, National Institute of Horticultural Research (NIHORT) Ibadan, Dr. A. Ano - Department of Soil Science, National Root Crop Research Institute (NRCRI) Umudike, Mr. S.O. Nti of the Department of Soil Science and Technology, Federal University of Technology Owerri and Engr. Enyema of the Department of Agricultural Engineering , Federal University of Technology Owerri. I owe them and their subordinates much appreciation for their varied roles in the completion of this work.

I am delighted to appreciate my wonderful colleagues Dr. I.I Ekpe, Dr B.U Uzoho, Dr Nkwopara, U.N., Dr. Mrs B.N Ndukwu, Dr. E.E. Ihem, Dr. S.U. Onwudike, Mr. L.C. Agim, Mrs F.A. Osisi, Mr. M.A Okon, and Mrs, C. M. Emenyeonu for their support, advice and encouragement.

My high indebtedness goes to my beloved husband Engr. Philip Ahukaemere, my lovely children (Nancy, Naomi and Joel), my brother-in-law and his wife Mr. and Mrs. Sylvester Ahukaemere for their immeasurable assistances and encouragement without which this work would not have been a success. Similarly, my appreciation goes to my father, Mr. G.A. Idigbor for his fatherly advice. Finally my thanks go to all those whose names are not mentioned here but have assisted in one way or the other. May the good Lord bless you all. Amen.

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

Appendix

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The study was conducted to determine carbon and nitrogen sequestration and dynamics in soils developed on different parent materials (Coastal Plain Sand, Falsebedded Sandstones and Shale) under different land use types (forest, fallow and cultivated lands) in South-eastern Nigeria. Geology maps were used to guide the location of sampling sites. Three parent materials and three different land use types in each of the parent materials were randomly selected. The study was a three factor experiment laid in a randomized complete block design (RCBD). A total of 27 profile pits were studied. Soil samples were collected from each of the profiles according to their horizons. Undisturbed soil samples for determination of bulk density were collected in core samplers. Small portions of the samples were air dried, crushed and sieved using a 2-mm sieve in preparation for laboratory analyses. Carbon and Nitrogen forms and sequestration, morphological and physico-chemical properties of soils were determined. Data were subjected to ANOVA , multiple regression, coefficient of variation and correlation analyses. From the results, carbon sequestration ranged from 3229 gCm^2 in Falsebedded sandstone-derived soils to 3648 gCm^2 in Shale-derived soils, and did not differ significantly across the soils. Nitrogen sequestration differed significantly ($p < 0.001$) with soils derived from Coastal plain sands having higher quantity (248.00 gNm^{-2}) while the least was recorded in soils formed from Shale (91 gNm^2). The C sequestration capacity of the soils of the different land use types varied significantly ($p < 0.05$) with fallow soils derived from Falsebedded Sandstone and Coastal plain sand containing the highest quantities (4753 gCm^{-2} , 4222 gCm^{-2}). Carbon and nitrogen sequestration increased with horizon thickness in all the profiles across the soils studied. The mean total carbon contents ranged from 39.20 to 82.80 gkg^{-1} across the soils and did not follow uniform pattern of distribution down the profiles, except in fallow soils of the Falsebedded Sandstone where it increased with depth. Soils derived from Shale had the least quantity of total carbon while those of Falsebedded Sandstone had the highest value. Forest soils had higher quantity of total carbon (109.20, 42.40 gkg^{-1}) compared to those of fallow and cultivated soils of the Falsebedded sandstone and Shale . Organic carbon constituted about 58% of total carbon in Shale-derived soils, 20.81% in Coastal plain sand and 27.66 % in Falsebedded sandstone – derived soils. In soils of the different land use types, forest soils contained significantly higher proportion of organic carbon, followed by fallow and lastly by those of the cultivated lands. Organic carbon correlated significantly with clay ($r = 0.513, 0.578$) ($p < 0.001$), WSA ($r = 0.506, 0.626, 0.646$) ($p < 0.001$) and BD ($r = - 0.537, - 0.900, -0.736$) ($p < 0.001$) respectively. The mean total nitrogen contents of the soils varied from 5.49 - 8.24 mg/kg in soils of dissimilar parent materials, 3.60 - 14.33 $mgkg^{-1}$, 7.33 – 8.87 $mgkg^{-1}$, 2.01 – 10.49 mg/kg in soils of the different land use types. Soils formed from Coastal plain sand and Falsebedded sandstone contained significantly higher ($p < 0.01$) quantity of total nitrogen than those of Shale. In soils of the different land use types, forest soils contained significantly higher ($p < 0.001$) proportion of total nitrogen (14.33, 10.49 $mgkg^{-1}$) than fallow and cultivated soils. Soils formed from Falsebedded sandstone and Shale had significantly higher ($p < 0.001$) proportions of available N compared to those of Coastal plain sand. In soils of the different land use types, forest soils had significantly higher proportion of available N compared to fallow and cultivated soils. Soils developed on different parent materials under different land use types had varying colour matrix ranges. Soil texture ranged from sand, loamy sand to sandy loam in soils derived from Coastal plain sand and Falsebedded Sandstone, loam, sandy clay loam, silt clay loam to clay in Shale-derived soils with soils formed from Shale containing significantly ($p < 0.001$) higher proportion of clay (263 gkg^{-1}) than those of Falsebedded sandstone (77 gkg^{-1}) and Coastal plain sand (90 gkg^{-1}). The mean bulk density (BD) values ranged from 1.06 to 1.22 gcm^{-3} in soils derived from the three parent materials. Forest soils had the least bulk density values (0.98, 1.09, 1.08 gcm^{-3}) compared to other land uses. In soils of different parent materials, Shale derived soils had highest percentage moisture content (12.49%) while those derived from Falsebedded sandstone had the least amount (9.09%). In soils under the three land use types, forest and fallow soils had significantly higher ($p < 0.001$) quantity of soil moisture than the cultivated soils. Shale-derived soils had significantly higher ($p < 0.001$) stable aggregates (29.23%, 1.35 mm) than those derived from Coastal plain sand and Falsebedded sandstone. In soils of the varying land uses, soils of the forest had significantly higher ($p < 0.001$) stable aggregates compared to those of fallow and cultivated lands. Soils were slightly acidic across the parent materials and land use types. Significantly ($p < 0.01$) least proportion of Calcium (Ca) (2.76 $cmolkg^{-1}$) was recorded in soils of the Falsebedded sandstones while those developed on Shale had the highest quantity (4.28 $cmolkg^{-1}$). Significantly higher percentage base saturation was obtained in soils derived from Shale (91.4%) while the least value was obtained in Falsebedded sandstone-derived soils (68.71%). Taxonomic classification was done to the Subgroup level. The soil classes derived from soil taxonomic classification of the USDA was correlated with the World Reference Base. Soils were classified as Grossarenic Kandiudults (USDA), Chromic Acrisols (WRB), Typic Kandiudults (USDA), Rhodic Acrisols (WRB), Lithic Kanhapludults (USDA), Rhodic Acrisols (WRB), Arenic Kandiudults (USDA), Chromic Acrisols (WRB), Vertic Paleudults (USDA), Haplic Acrisols (WRB), Entic Paleudults (USDA), Haplic Acrisols (WRB), Psammentic Hapludults (USDA), Arenic Acrisols (WRB).

Keywords: Carbon Sequestration, Land Management Practices, Land use on Carbon Sequestration, Recycling, South East, Nigeria.

CHAPTER ONE

1.1 INTRODUCTION

Soils are important reservoirs of active organic components (such as carbon, nitrogen) and play a major role in the global cycle of these elements. As such, soil can be either a source or sink for atmospheric carbon dioxide (CO_2) depending on land use and management of soil and vegetation (Lal, 2005). Over 60% of the world's carbon is held in both soils (more than 40%) and the atmosphere (as carbon dioxide; 20%) (Stevenson, 1994).The conversion of native ecosystems such as forests, grasslands and wetlands to agricultural uses, and the continuous harvesting of plant materials, have led to significant losses of plant biomass and carbon (Davidson and Ackerman, 1993), thereby increasing the carbon dioxide (CO_2) level in the atmosphere. However, soil disturbance is redistributing the carbon, augmenting the atmospheric carbon pool. Thus, a part of carbon increase in the atmosphere is thought to have come from agriculture, affecting not just climate change but also productivity and sustainability of agriculture and natural resources (Robbins, 2004). The value of soil for agricultural and other uses is majorly determined by the concentration of organic components of the soil and parent materials from which the soils are formed.

Carbon sequestration involves the process of transferring atmospheric CO_2 into the soil through crop residues and other organic solids, and storing it securely so it is not immediately re-emitted into the atmosphere (Lal, 2004). Thus, soil carbon sequestration means increasing soil organic carbon (SOC) and soil inorganic carbon (SIC) stocks through judicious land use and recommended management practices (Akamigbo, 2010a). This transfer or "sequestering" of carbon helps off-set emission from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long term agronomic productivity. Soil carbon sequestration can be accomplished by management systems that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil fauna activity. A major challenge facing scientists and policy makers is how to increase the amount of carbon sequestered in soil in order to mitigate climate change. Global climate change is a long-term energy and environmental challenge requiring major investments in targeted research and development. Gaining a greater knowledge of how carbon cycles through ecosystems is a critical element of the national strategy to understand climate and potential changes that might occur due to anthropogenic greenhouse gases and to develop solutions to reduce future increases in CO_2 (the most important Green House Gas (GHG)) and other GHGs (Forge,2001). Understanding how climate affects both natural and managed "pools" (e.g., forest, agriculture lands) of carbon stored in global ecosystems and how these carbon "sinks" influence atmospheric concentrations of CO_2 will be important in reducing uncertainty in climate models and in understanding the long-term sequestration capacity of those pools.

The rapidity of soil carbon decline in tropical soils is worrisome as it is a principal factor in soil quality of the biome which results to soil structural deterioration. Poor carbon sequestration has been attributed to shortened fallow cycles, poor management practices, changes in microbial chemistry, bush burning, deforestation, conventional tillage, mining, climate change and poverty (Onweremadu *et al*., 2008a). Of all the causes of poor carbon sequestration in the soil, deforestation takes a great toll in sub-Saharan Africa, and indeed the tropical world. In Southeastern Nigeria, there is increased deforestation and resultant erosion damages of soil resources (Oti, 2007). However, in the tropics, erosive activities have led to a decline in organic matter (Mbagwu and Obi, 2003), resulting to adverse changes in physical properties of the soils, low nutrient status and build-up of toxicities such as excessive concentration of heavy metals in soils. In the light of the above, several soil fertility enhancing practices such as prolonged fallow, conservation tillage and improved agro-forestry systems have been suggested with little success due to increasing population and poverty which consequently result to pronounced degradation of soil resources (Mbagwu and Obi, 2003).

Human induced soil degradation is an important cause of the decline in productivity of many soils. Experience in Europe and most developing countries like Nigeria has shown that the vulnerability of soils to specific type of degradation differs widely according to land use. Some soils are vulnerable to erosion by water, ice or wind, others to physical compaction or chemical degradation (Batjes and Bridges, 1993). In large parts of the tropics, chemical soil degradation is caused by the depletion of plant nutrients (Hartemink and Bridges, 1995), poor carbon sequestration and low soil organic matter content of the soils resulting from unsustainable agricultural activities. Unless nutrients removed by agricultural crops are replaced, either naturally through weathering and bio-geocycling, carbon sequestration or by the use of fertilizers, the soil nutrient reserve will gradually be depleted. Human-induced loss of nutrients was estimated to be affecting 45 million hectares in Africa and 135 million hectares worldwide (Oldeman *et al*., 1991).

The contributions of soil carbon on physical, chemical and biological properties of soils and thus in sustaining their productivity have been appreciated since the dawn of human civilization. Important factors that control soil carbon levels include climate, hydrology, soil fertility, biological activity, vegetation patterns and land use (Bahattacharyya *et al*., 2000). Soil organic carbon is sensitive to human activities such as deforestation, biomass burning, land use changes and environmental pollution. Rapid degradation of arable soils in Nigeria due to anthropogenic factors and the attendant decline in farm productivity have brought about renewed focus on the need to cultivate the hitherto little-exploited arable soils (Izak *et al*., 1990; Eshett, 1993). In most cases, soils are mined, leading to low organic matter content (Onweremadu, 2006). There is abundant literature in the humid tropics on changes in soil physico-chemical properties following deforestation, subsequent land cultivation and soil parent materials (Akamigbo, 1999a; Sisti *et al*., 2004; Walker and Desanker, 2004; Onweremadu *et al*., 2007a). However very few are concerned with the dynamics of organic components and their sequestration in soils of dissimilar lithology under forested, continuously cultivated and fallow lands. Information on nutrient dynamics is not only necessary to make good land use decisions in agriculture, but also it is a pre-requisite to understanding gaseous exchanges between soil and atmospheric systems, especially in this era of global warming and climate change. Recent concerns about greenhouse gases (carbon dioxide (CO_2) and nitrous oxide (N_2O)) and damage to the ozone layer have resulted in more studies on the inputs, outputs and storage of carbon and nitrogen in different terrestrial systems. Carbon and nitrogen are in dynamic equilibria in soil and an increase or decrease in one may result in an increase or decrease in the other. To sustain the quality and productivity of soils, a good knowledge of soil organic components in terms of their concentrations, dynamics and qualities is indispensable. Assessments of the distribution of carbon within and among soil types are critical to developing an understanding of the cause and effect relationships between climate, land use change and release of CO_2 to the atmosphere (Schimel *et al*., 1985). However, proper knowledge of carbon sequestration is critical when developing carbon budgets and explaining the cause and effects of climate change, and for basic ecosystem characterization (Alleta *et al*., 2004).

In addition, classification of soils of any given location helps in generating soil and soil-related data which are useful in predicting soils for their sustainable uses (Onweremadu *et al.*, 2007b). Appropriate and proper use of soils depends upon the characteristics of such a soil. There is therefore a need to characterize and classify them in a manner that will ease communication and transfer of knowledge about such soils to farmers and other land users (Nuga *et al.*, 2008). On the basis of organic matter content, soils are classified as mineral (inorganic) or organic soils (Food and Agricultural Organization (FAO), 2005). Mineral soils form most of the worlds cultivated land and may contain from trace to 30% organic matter (Soil Survey Staff, 2003). Organic soils are naturally rich in organic matter containing more than 30% organic matter principally for climatic reasons and are not vital cropping soils.

There is need to understand the impact of land use management on soil carbon stocks regionally and globally, because this stock is not only twice the total amount of CO_2-C in the atmosphere, but it is also sensitive to land use changes (Wu, 2011). More so, restoration of soil quality through soil organic carbon management has remained a major concern for tropical soils. To make this successful, the comprehensive knowledge of the sequestration and dynamics of carbon and nitrogen in the tropical soils should form an essential pre-requisite in future land resource management programmes. However, knowledge of the amounts, forms and distribution of these elements is essential in understanding nutrient dynamics in soils of a densely populated central south-eastern Nigeria and its relationship to global nutrient cycles. In view of this, the major objective of this work was to study the sequestration, forms and dynamics of organic components (carbon and nitrogen) of soils of dissimilar parent materials under three different land uses.

The specific objectives were to:

- characterize and classify soils of the study area using USDA Soil Taxonomy and World Reference Base (WRB).
- determine carbon and nitrogen forms in the soils derived from different parent materials under different land use types.
- determine the quantities and variations of carbon and nitrogen sequestered by the soils derived from different parent materials under different land use types
- estimate the degree of association between soil organic fractions and selected properties of the soils under study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Carbon sequestration

Carbon sequestration implies transferring atmosphere CO_2 into long-lived pools and storing it securely so it is not immediately re-emitted into the atmosphere (Lal, 2004). Thus soil carbon sequestration means increasing soil organic carbon (SOC) and soil inorganic carbon (SIC) stocks through judicious land use and recommended management practices. Observed rate of SOC sequestration in agricultural and restored eco-systems depends on soil texture, profile characteristics and climate, and ranges from 0-150 kg C/ha per year in dry and warm regions and 100 – 1000 kg C/ha per year in humid and cool climate (Lal, 2004). Soil organic carbon sequestration is caused by those management systems that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, enhance activity and species diversity of soil fauna, and strengthen mechanism of elemental cycling. The rate of soil inorganic carbon sequestration as secondary carbonate is low and accentuated by biogenic processes and leaching of carbonates into the ground water especially in soils irrigated with water containing low carbonate.

Currently, the biosphere constitutes a carbon sink that absorbs about 2.3 gigatones of carbon per year, which represent about 30% of fossil- fuel emissions. The increasing atmospheric CO_2 concentration stimulates the process of photosynthesis and consequently plant growth, as extensive experimental research has shown (Intergovernmental Panel on Climate Change (IPCC), 2000). Forests stimulate more than pastures and crops in the proportion of 60 % to 14 %. Forests in the absence of disturbance are expected to take up carbon for 20-50 years after establishment and, therefore, they should be considered as a time-buyer until other technologies are developed to reduce emissions. Carbon sequestration is not an option to reducing dependence on fossil fuel, the cause of the problem of climate change in the first place. Carbon sequestration should be seen as a bridge until other acceptable and environmentally friendly alternatives are found (Intergovernmental Panel on Climate Change (IPCC),2000). Soils are the largest carbon reservoir of the terrestrial carbon cycle. The quantity of carbon stored in soils is highly significant; soils contain about three times carbon than vegetation and twice as much as that which is in the atmosphere (Batjes and Somnbroek, 1997).

Terrestrial sequestration (sometimes termed biological sequestration) is typically accomplished through forest and soil conservation practices that enhance the storage of carbon, such practices include: restoring and establishing new forest, wetlands and grassland, or reduce CO_2 emission (such as reducing agricultural tillage and suppressing wild fires). Generally, these practices are implemented to meet a variety of land management objectives. Although the net terrestrial uptake fluxes offset about 30% of fossil fuel CO_2 emissions, only a small fraction of this uptake results from activities undertaken specifically to sequester carbon. The largest net uptake is due primarily to on-going natural re-growth of forests that were harvested during the 19th and early 20th centuries (United State Geological Survey (USGS), 2011). Existing terrestrial carbon storage is susceptible to disturbances such as fire, disease, and changes in climate and land use. According to USGS (2011) report, boreal forest and Northern peat, which store nearly the total terrestrial carbon in northern America are already experiencing substantial warming resulting in large scale thawing of permafrost and dramatic changes in aquatic and forest ecosystems. Also, United State Geological Survey scientists have estimated that at least 10 gigatons of soil carbon in Alaska are stored in organic soils that are extremely vulnerable to fire and decomposition under warming conditions.

Therefore any decision about terrestrial carbon sequestration must require careful consideration of priorities and trades offs among multiple resources. For example, converting existing conservation lands to intensive cultivation, while perhaps producing valuable crops (for example, for bio-fuel) may diminish wildlife habitat, reduce water quality and supply, and increase CO_2 emissions. However, few promising ways to promote carbon sequestration is to encourage organic farming practices, increase organic inputs into farm soils and encourage minimum tillage farming systems. Not only do organically rich soils sequester CO_2, they also have higher crop yields and lower fertilizer input requirement thereby reducing carbon dioxide (CO_2) emissions.

2.1.1 Quantification of soil carbon sequestration

When soil samples are analyzed for carbon sequestration, the result is conventionally expressed in units such as percentage (%), milligram of carbon per kilogram of soil (mg C kg^{-1}) or micogram of carbon per kilogram of soil (μg C kg^{-1}) (Powlson *et al*., 2011). These are units of concentration, though they are often incorrectly referred to as C contents. To express C as a quantity or content rather than concentration, concentration has to be multiplied by the mass of soil to a given depth, often determined from measurement of bulk density (Powlson *et al*., 2011). Soil carbon sequestration can then be expressed in units such as milligram of carbon per hectare (mg C ha^{-1}) or gram of carbon per meter square (g C m^{-2}) to the defined depth. When expressed in such units the quantity of C in 1 ha of soil can correctly be termed a C stock. Alternatively, the value may be multiplied by an area of interest such as Europe, Nigeria etc often in units of pico gram (Pg). A term frequently used in such studies is 'C density', which is synonymous with 'C stock per unit area'. However, this is best used when computing the carbon sequestration in a large region. Thus Cerri *et al.,* (2007) used this term when describing the distribution of carbon stocks within the Amazon region . This shows that some areas had a C density in the range 100–150 milligram per hectare (mg ha^{-1}) whilst others were < 40 mg ha^{-1}.

Different researchers also adopted different methods to determine carbon sequestration depending mainly on their research objectives. Abebayehu, (2013) determined carbon sequestration capacity of forest soils in Kafa zone Bita District, South-western Ethiopia by multiplying the bulk density, organic carbon concentration and horizon thickness of the soil. The amount of carbon stored (ton per hectare) (tha^{-1}) in each profile was obtained by summing up the carbon stored in different horizons of the respective profiles. He found out that carbon sequestration capacity was significantly affected by organic carbon concentration, sampling depth and bulk density. He also stated that a unit rise in soil organic carbon concentration, bulk density and sampling depth raises soil carbon sequestration by 5.47, 1.53 and 25.64 tha^{-1} respectively, Linda *et al*., (2003) used similar method to determine the potentials of US forest soils to sequester carbon; and also observed increased carbon sequestration with increased soil depth, bulk density and organic carbon. Mba and Idike, (2011) used % C /100 x bulk density x area (tha^{-1}) x soil depth (0-5, 5-20 cm) to determine carbon sequestration in tropical agricultural soils of South-eastern Nigeria under different management practices; and reported highest total carbon storage in natural forest and alley cropping with 37%, 62%, and 27% increase relative to sewage sludge dump site and *Gmelina arborea* forest. They further stated that alley cropping and forests can store large quantities of carbon in soils while sewage sludge is not effective in storing large quantities of carbon. Anikwe, (2010) used similar method (C (%)/100 x soil bulk density x soil depth x area (t/ha); and reported highest carbon stocks (7906-9510 gCm^{-2}) in artificial grassland, natural forest and artificial forest ecosystems while continuously cropped and conventionally tilled soils had about 70% lower carbon stock (1978 – 2822 gcm^{-2}).

Batjes (1996); Brahim *et al*., (2010); Bermoux *et al*.,(2002) used Carbon storage (gCm^{-2}) = ∑Dbi x Ci x Di where Dbi = bulk density (Mgm^{-3}) of layer i, Ci = proportion of organic carbon (gCg^{-1}) in layer i and Di is the thickness of this layer (cm) to determine the carbon sequestration of individual profile. He reported carbon sequestration value of 684 -728 Pg C in the upper 30cm, 1462 -1548 Pg C in the upper 100 cm. and 2376 – 2456 Pg of carbon in the upper 200 cm. Also, Brahim *et al*., (2010) reported lower carbon stocks (405.44 TgC (1 Tg = 10^{12} g) at the upper soil layer 0-30 cm while 0-100cm contained higher carbon stock (1006.71 TgC). He also stated that based on soil types, Luvisols contained 7.16 and 15.92 $kgCm^{-2}$ for 0-30 cm and 0 - 100 cm while the lowest carbon stocks were found in the Lithosols to be 1.84 $kgCm^{-2}$ for 0-30 cm and 4. 04 $kgCm^{-2}$ for 0 -100 cm.

When quantifying a change in soil C stock, by comparing measurements taken at two times or by comparing two treatments or land uses, it is essential to take account of any change in soil bulk density that has occurred. A relatively simply way of achieving this is to sample soils on an ‘equivalent mass basis’ (sometimes termed ‘equivalent depth’). This is important when there is likely to have been a change in soil bulk density (either over time or between treatments) and when, as is usually the case, the entire profile is not sampled. The principle is that an equal mass of organic-matter-free mineral soil should be sampled between the treatments or times being compared. Thus, if an arable soil is converted to grass or forest, the increase in organic matter content will generally cause a decrease in soil bulk density. So if the soil was sampled to a depth of H cm at time 1, the depth containing the same mass of mineral soil at time 2 will be slightly greater.

Conversely, a change in arable practice from conventional tillage to zero tillage generally leads to a small increase in bulk density, if the conventionally tilled soil was sampled to depth H cm (which should be slightly greater than cultivation depth), it is necessary to sample the soil after a period of zero tillage to a slightly shallower depth in order to compare equal masses of mineral soil and correctly quantify any change in soil C stock. It was used by Hopkins *et al*, (2009) in assessing possible changes in C stocks in grassland soils over time, and by Powlson and Jenkinson, (1981) in comparing C stocks in arable soils under conventional and zero tillage. Powlson and Jenkinson, (1981) reported higher carbon stocks in zero tillage than conventional tillage practice.

In view of these, the quantification of soil carbon sequestration using organic carbon, bulk density and depth (horizon thickness) is mostly used in studies involving natural horizonation and layering and would be adopted in this study.

2.1.2 Potentials of different agricultural practices to sequester carbon in soils

According to Lal (2004), estimate of total potential of carbon sequestration in world soils varies widely from a low range of 0.4 - 0.6 Gt C/year to a high range of 0.6 - 1.2 Gt C/year. Thus, the potential is finite in capacity and time, nonetheless, C sequestration is a method of buying time until the alternative to fossil fuel takes effect. The long-term carbon retention capacity of soil depends on sound land management. Soil sinks cannot be created unless practices are adopted that increase the carbon content of the soil. Those practices, which can vary depending on the type of soil and climate, include: increase in the amount of land left fallow; the use of direct drilling (conservation tillage), which does not disturb the soil as much and reduces the amount of CO_2 released into the atmosphere; the use of legumes in crop rotation; the conversion of marginal farmland to perennial grasses or trees; the use of rotation grazing and high-intensity short-term grazing; mulch farming, agro-forestry and diverse cropping systems, cover crops, and integrated nutrient management, including the use of manure, composts, bio-solids, improved grazing and forest management, the planting of shrubs and trees as windbreaks; and the restoration of wetlands (Forge, 2001). Others include water management, irrigation, improved farming systems with several crop rotations, integrated water-shade management and restoration of wetlands. The efficacies of some of the management practices in sequestering carbon in soil are presented in Tables 2.1 and 2.2, respectively. Many management methods aimed at storing carbon in soil sinks also contribute to environmental sustainability. Increasing the organic matter content of soil helps improve soil’s agronomic capabilities. It also produces better soil and better crops, improves water conservation, reduces erosion, and improves wildlife habitat and species protection, leading to greater biodiversity (Forge, 2001).

Table 2.1: Land use and land management determining whether soil will be a sink or source of atmospheric carbon dioxide (CO_2).

Soil as a source of CO_2	Soil as a sink for CO_2
Soil properties: coarse textured soil, excessive drainage, high susceptibility to erosion	Soil properties: clayey soil, poorly drained ecosystems, deep soils, depositional sites, including foot slopes
Land use: seasonal crops, simple ecosystems, shallow roots and low root-shoot ratio.	Land use: perennial crops, diverse ecosystem, deep roots and high root-shoot ratio
Soil management: intensive tillage based on plough, negative nutrient balance residue removal and/or burning, continuous cropping, loss of soil and water by runoff and erosion	Soil management: no tillage, positive nutrient balance, mulch farming, cover crops in rotation cycle, soil and water conservation.

Source: Adapted from Lal, (2005)

Table 2.2: Effects of land management practices and land use on carbon sequestration (t/ha/yr) – Tropical area.

Land management practices	Tropical areas
Crop land (700 million ha)	2 billion ha
Conservation tillage	0.2 -0.5
Mulch farming or plant cover	0.1 - 0.3
Conservation agriculture	0.3- 0.8
Composting	0.2 -0.5
Nutrient management	0.2-0.5
Water management	-
Grassland and pastures (3 billion ha)	0.1-0.2
Afforestation	4 – 8
Agro-forestry (1 billion ha)	0.2-3.1

Source: Lal, (1999). Global carbon pools and fluxes.

Soil carbon sequestration through the adoption of agricultural practices broadly known as "conservation agriculture" is an important means by which the process of global climate change may be mitigated (Lal, 1999 ; Batjes, 1999). At the same time, the agricultural practices used to supply soil carbon sequestration often lead to more profitable and sustainable agricultural production systems for both small and large producers, characterized in many cases by more stable and higher agricultural yields (FAO, 2004). Additionally, environmental benefits in the form of an improved ecosystem functioning are also commonly associated with such agricultural production systems (FAO, 2004; FAO,2001). Soil carbon sequestration is of particular interest in the context of food security and poverty alleviation, since degraded lands in dry land areas are good potential source of carbon sequestration, with the potential to simultaneously increase agricultural productivity in areas characterized by high poverty incidence and limited options to improve livelihood outside of the agricultural sector (Weibe, 2003). The potential rate of carbon sequestration is sensitive to agro-ecological conditions, with higher rate in humid temperate areas than semi-arid and tropical areas (Pretty and Ball, 2001; Lal, 1999). According to Lal, (1999), the adoption of conservation agriculture techniques that involves reduced tillage and coverage of at least 30% of the land area can be expected to generate 0.5 -1 ton C/ha/yr in humid temperate conditions, 0.2 – 0.5 ton C/ha/yr in humid tropics and 0.1 – 0.2 ton C/ha/yr in semi-arid zones (Lal, 1999). However, carbon can be introduced into the soil in the following ways: conservation tillage, use of agricultural chemicals and nutrient recycling, afforestation and use of organic wastes.

2.1.2.1 Conservation tillage practices and carbon sequestration

The role of agriculture in society is changing in industrialized and developing countries. Rather than being considered only as a means to produce food, it is becoming a solution to adverse weather conditions and ecosystem services. These ecosystem services are related to soil functions and for this reason, the fact of promoting farming systems that produce both food and ecosystem services is becoming more important (Lal, 2007). Lal (2007) consider an increase in soil organic carbon sequestration as a crucial factor in enhancing soil, air and water quality. Management practices that increase C inputs in farming systems should increase SOC (Kong *et al.*, 2005, Denef *et al.*, 2004). It is well established that increases in soil carbon are accompanied by increased soil aggregation, plant available water capacity, ion exchange capacity and soil biodiversity (Lal and Bruce, 1999), and crop yield (Pretty and Ball, 2001).

Conservation tillage is a tillage system with reduced tillage practices and where crop residues are left on the soil surface to minimize water runoff and soil erosion, enhance desirable soil structure (Foth, 1990) and encourage soil carbon accumulation. Conservation tillage makes use of conserved tillage practices to reduce excessive disturbance of the soil and to maintain the crop residues on the soil surface in other to minimize damage to the environment and provide organic carbon and nutrient. If minimizing soil disturbance decreases soil organic carbon decomposition rate, then this change in management practice would cause decreased transfer of C from soil to the atmosphere and so be a genuine climate change mitigation. However recent reviews of data comparing conventionally cultivated soil and soil receiving minimum or zero tillage have shown difference between the systems in the total amount of soil organic carbon present, provided account is taken of soil organic carbon variation with depth and differences in bulk density (Baker *et al*., 2007; Angers and Eriksen-Hamel, 2008). According to FAO (2005), conservation tillage is based on four principles; minimal mechanical soil disturbance, permanent soil cover, reduced erosion problems and minimal soil compaction which are applied together to generate positive outcomes. The conversion of native ecosystems to agricultural uses, continuous harvesting of plant materials and use of heavy machines have led to significant losses of plant biomass and carbon (Davidson and Ackerman, 1993), thereby increasing the CO_2 level in the atmosphere. Davidson and Ackerman further reviewed that the practice of burning agricultural fields and the use of heavy machines before and during cultivation has a disastrous effect on soil organic C content.

Reduced tillage, combined with crop residue retention (conservation tillage), is a farming practice that can increase SOC and improve soil structure and soil stability while facilitating better drainage and water holding capacity; limiting the potential for water logging and drought (Lichter *et al*., 2008; Zibilske and Bradford 2007; Govaerts *et al*., 2007). Conservation tillage counters the adverse effects of conventional tillage, namely reduced carbon sequestration, the destruction of soil aggregates, which reduces the soil's ability to hold plant available water (Patino-Zuniga *et al*., 2008). Also when soil aggregates are destroyed by tillage and conventional ploughing, soil organic matter becomes available for decomposition (Bronick and Lal, 2004), thus decreasing the organic matter content of the soil. Patino-Zuniga *et al*., (2008) found that disturbing a Mollisol in Mexico to make beds for a maize-wheat rotation decreased soil organic carbon content within 6 years by 10% compared to soil under non-tilled beds. The Intergovernmental Panel on Climate Change (2000) reported increases of 0.32 t SOC/ha/yr; while in Brazil, soil carbon sequestration was increased by conservation tillage when maize was rotated with Mucuna (15.5 Mg CO_2 ha^{-1}) during 8 years, compared to a net emission of 4.32 Mg CO_2 ha^{-1} from traditional maize/fallow plot (Evers and Agostini, 2000). Thus soil conservation practices (such as minimum tillage, rotations, cover cropping and fallowing) result in soil carbon accumulation.

However, systems based on high crop residue addition and no tillage tend to accumulate more C in the soil than it is lost to the atmosphere. Carbon sequestration in managed soils occurs when there is a net removal of atmospheric CO_2 because carbon input exceeds carbon output (Izaurrallde and Cerri, 2002). Edwards *et al*., (1992) reported that conversion from conventional tillage to conservation tillage in soybeans and corn systems rotated with wheat increased soil carbon on average by 30% over a 10 year period. In conservation tillage, more C can also be stored by adding leguminous and other crop residues to the soil. Besides enhancing C sequestration to the soil, legumes add a substantial quantity of nitrogen to the soil, which results in increased biomass production of succeeding crops. Brito *et al*., (2005), reported significant influence of soil temperature on CO_2 emission. High soil temperature accelerates soil respiration and thus CO_2 emission, therefore leaving the soil under cover ameliorates soil temperature, encourages C sequestration and reduces green house gas emissions. Figure 2.1 shows the difference between amount of carbon accumulated in conventional and conservational tillage.

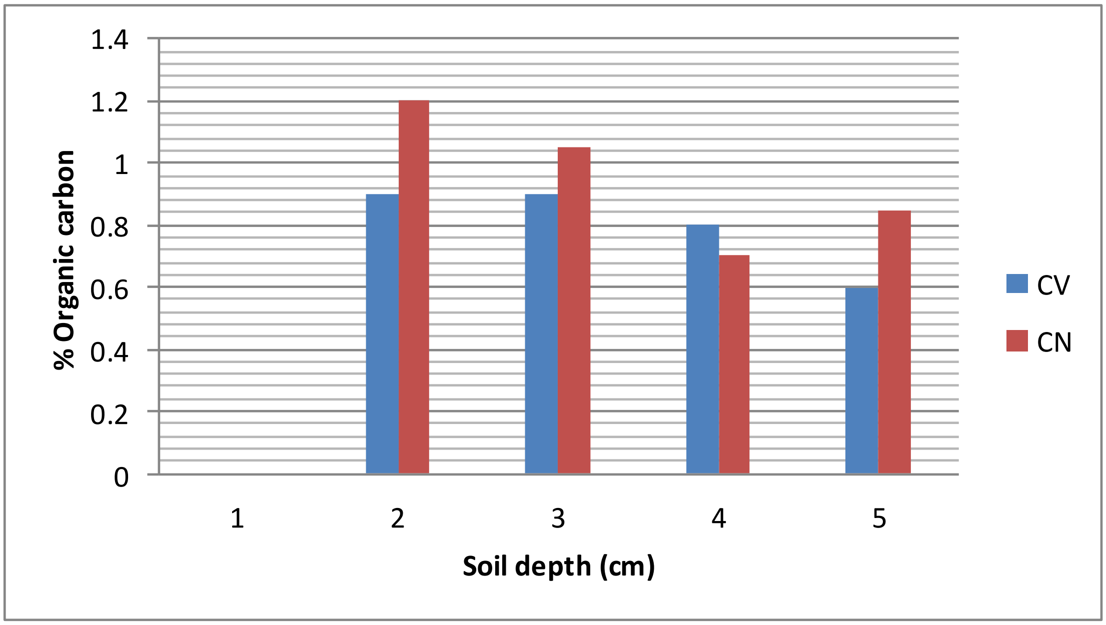


Fig. 2.1: Conservational tillage(CST) and conventional (CNT) tillage, after two cropping cycles.
Source: Prior *et al*., (2003).

2.1.2.2. Use of agricultural chemicals and nutrient recycling

In nutrient poor situations the addition of fertilizer has been proposed as a way to enhance soil carbon storage due to the resulting increase in plant production and litter return to soil, and through suppressing microbial decomposition of recalcitrant organic matter. Evidence for this, however, is mixed, in that fertilization of agricultural soils has been shown, in some situations, to enhance organic matter decomposition. Most recommended management practices that involve the use of C based inputs to enhance yield, which in turn add C to the soil include, 0.86 kg C/kg N, 0.17 kg C/kg P_2O_5, 0.12 kg C/kg K_2O, 0.36 kg C/kg lime, 4.7 kg C/kg of herbicides, 5.2 kg C/kg of fungicides and 150 kg C/kg/ha for pumping ground water for irrigation (Akamigbo, 2010b). These inputs add considerable amount of carbon to the soil, thus increasing soil C stock (Follet, 2001). Carbon sequestration demands the use of biological N fixation, recycling from subsoil, use of bio-solid wastes, composts, crop residues, treated municipal wastes etc to boost the soil carbon stock. Crop residues can be incorporated into the soil instead of burning them. These practices, not only enhance the soil carbon content, also release important nutrients to the soil and improve structural stability of the soil. The annual depletion rate of nutrient for sub-Saharan Africa caused by low-input/subsistence farming is estimated to be 40 kg of NPK/ha of cultivated land since mid 1960s (Sanchez, 2002). Mining SOC from soils for nutrient through organic matter decomposition has an effect on the atmosphere similar to that of fossil fuel combustion. The recommended management practices must enhance rather than deplete SOC pool and soil fertility, increase rather than decrease crop yield per unit use of fertilizer and other inputs, and improve rather than degrade soil quality. In systems where crop residues are managed well, they: add soil organic matter, which improves the quality of soil, and increases the water infiltration and retention capacity of the soil, buffers the pH and facilitate the availability of nutrients; sequester C in the soil; provide nutrient for soil biological activity and plant uptake; capture the rainfall on the surface and thus increase infiltration and the soil moisture content; reduce evaporation and avoid desiccation from the soil surface (FAO, 2005).

Another possible way to enhance soil carbon sequestration involves the manipulation of plant-soil feedbacks, especially in grassland. For example, Potter *et al.*, (1999) reported that increased plant diversity and the introduction of certain plant species such as legumes into mixed grasslands, can reap benefits for soil carbon sequestration. The mechanisms involved in plant manipulation of soil carbon sequestration are complex and involve many types of biotic interactions between plants, their symbionts, and decomposers. However, it is becoming clear that a research effort focusing on plant traits (and especially of roots), offers a potential way forward for understanding how plant-microbial-soil interactions might be manipulated to enhance soil carbon storage.

2.1.2.3. Afforestation and/or reforestation

Climate change, land use change and world forest are inextricably linked. Man made emissions of the Green House Gas (GHG), CO_2, into the earth atmosphere continue to escalate. Forest covers more than 4 billion hectares of the earth's land surface area and contain huge reservoirs of C in their vegetation and soils (Percy *et al.*, 2003). Forest ecosystems store more than 80% of all terrestrial aboveground C and more than 70% of soil organic carbon (Batjes, 1996, Jobbagy and Jackson, 2000, Six *et al.*, 2002). According to the Kyoto protocol (KP), carbon sequestration in terrestrial sinks can be used to offset GHG emissions. Forests absorb 7-12 % of CO_2 emissions with agricultural land being a source and forest a sink of CO_2 (Janssens *et al* 2003). The KP states in article 3.3 that "net changes in GHGs emissions by sources and removals by sinks resulting from direct human-induced land use changes and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments." Understanding the role of forest in C cycles and predicting whether they will be C sinks or sources in the future are important to ongoing international dialogue on the subject of climate change. In the year 2000, approximately 30% (3869 Mha) of the earth's land area was covered by forest, almost half of the forested lands are in the tropics, a third are in the Boreal region, and approximately 10% are in each of the subtropical and temperate forest regions (Percy *et al.*, 2003). The proportion of the world terrestrial surface that is forested has been changing as a result of anthropogenic activities, among the consequences was a reduction of soil C pool (Robert *et al*, 2007). For instance, during the decade 1990-2000, the forested area within the tropics decreased by 14.2 Mha per year, primarily because of deforestation (Percy *et al.*, 2003). Coincidentally, the forested area increased by 1.7 Mha/year in non tropical forest mainly from natural expansion.

Forests are large reservoirs of carbon as well as potential C sink and sources to the atmosphere. According to Bolin *et al* (2000), forests have a higher C density than other types of ecosystems. Globally, forests play a significant role in the global carbon cycle, having absorbed approximately one third of recent anthropogenic CO_2 emissions to the atmosphere. Through the process of photosynthesis, forests capture C from the atmosphere, convert the photosynthate to forest biomass and emit C back into the atmosphere during plant respiration and decomposition. The annual CO_2 exchange between forest and the atmosphere via photosynthesis and respiration is approximately 50 Pg C/yr, that is 7 times the anthropogenic C emission (Robert *et al* ., 2007). These exchanges of carbon between forest and atmosphere are influenced by human cause and natural disturbances. This forest-atmosphere interaction leads to the view that controlling land use practices involving forest might prevent to some degree the increase in atmospheric green house gases and additionally, that some forest management activities might effectively reduce the rate of CO_2 accumulation in the atmosphere. According to Bosquet *et al*., (2000) in temperate north America, forest C sinks are believed to offset a significant proportion of C emission associated with fossil fuel combustion. In the United States for instance, forest C sinks have been estimated to offset up to 24% of the fossil fuel source (USDA Forest Service, 2001). Thus the ability to monitor forest C sequestration is of great interest in relation to understanding the status of global C cycle and to meeting requirement in the United Nations convention on climate change to quantify C sources and sinks associated with land use (UNFCC, 1992, Parson *et al*., 1992).

The afforestation of agricultural land increases the C pool in the aboveground biomass and replenishes the soil C pools. Accumulation of C occurs until the soil reaches a new equilibrium between C inputs (litter-fall, rhizodeposition) and C output (respiration, leaching). Post and Kwon, 2000 reported that the average rate of soil C sequestration was 0.3 t C/ha/yr (range 0-3 t C/ha/yr) across different climatic zones. On average, afforestation increases total C stocks by 18% over a variable number of years (Guo and Gifford 2002). Afforestation is a widely embraced C sequestration technique. However, its capacity in sequestering C is limited by competition with other land use purposes such as arable farming. In addition, as forest and underlying soil mature, the carbon sink becomes saturated. If the trees are cut or burnt, the stored C will be lost back into the atmosphere. Human population growth and agricultural expansion in conjunction with wood harvesting for fuel and export have led to increase deforestation rate

(Olatilu and Oke, 2010). Approximately, 65% of the land in the tropical world, which is home of over 630 million people is susceptible to such degradation (King, 1979). According to Olatilu and Oke, (2010), the interactions among different tree species in the forest encourages C sequestration, nutrient cycling and retention as well as moderation of micro climate. From the perceptive of climate change, forestry is attractive for two reasons, the first is that the tree component fixes and stores C, because trees are perennial plant and can function as active C sinks for periods of many years. A second interest is its apparent potentials to reduce raindrop impact and runoff which has drastic influence on C storage in the soil. Globally, forest management practices (afforestation, reforestation, agro-forestry etc) are indispensable for efficient C sequestration in soil. Kyoto protocol (KP) article 3.4 allows the use of forest management for C sequestration up to nationally applicable limit (UNFCC, 2002., Cannell, 2003).

2.1.2.4. Fallow system and age of fallow

Type and age of fallow (vegetation) are important factors that influence carbon sequestration in soil. According to Brye and Kucharik (2003), changes in ecosystem can increase or decrease soil carbon sequestration capacity. Follett *et al.,* (2001) reported that fallowing which has been defined as taking land out of agricultural production and permitting natural vegetation to grow, is a common traditional method of soil fertility restoration and soil organic carbon sequestration. Agronomists have long recognized the benefits of maintaining and increasing soil carbon through fallow systems which add to soil fertility, water retention and crop production (Mba and Mbagwu, 2003). Carbon enters the soil through dead roots, litter, harvest residues and animal manure (Mba and Idike, 2011). Lal (2004), observed that the ability of soil to capture and secure storage of carbon is a function of farming system and management. Brye and Kucharik, (2003) observed decrease in amount and rate of C and N sequestered as the age of ecosystem increased. They further reported that decline in the amount and rate of C and N sequestered in soil as vegetation age increased suggests that C and N sequestration potential decreases over time as the amount of soil C and N reaches a new equilibrium. However, it is clear that the annual rate of carbon sequestration in soil is much greater in the early years after land use change from cultivated to fallow and then gradually decreases as fallow age increases

(Johnston *et al*., 2009; Poulton *et al*., 2003). Potter *et al*., (1999), Knops and Tilman, (2000), also revealed the influence of vegetation age on carbon and nitrogen sequestration. Fallowing (both natural and improved) has also been identified by several authors as an effective management practice in carbon sequestration (Tian *et al*., 2001, Six *et al*., 2004, Raji and Ogunwole, 2006). Raji and Obidike (2011) reported a decline in soil carbon storage after 12 years of fallow; thus revealing that the resilient power to self restoration of degraded lands decreases with increasing fallow period

2.1.2.5. Recycling and application of organic waste

A consequence of poor agricultural practices in the past is that many soils in the world have lost more than half of their carbon stores (Dalal and Chan, 2001). Organic carbon is a significant component of organic waste and its application to soils should increase soil organic carbon (Zinati *et al*., 2001), thus enhancing carbon sequestration in soil. According to Poulton, (1995), the annual applications of 35 t/ha (fresh weight) farm yard manure increased soil carbon sequestration to over 3% compared to 1% in non-manured soil. The amount of carbon sequestered by organic wastes should be governed by the factors controlling soil organic carbon dynamics (climate, soil type and management practices); additional factors including the nature (chemical composition) of the organic waste applied, which will influence the rate of subsequent carbon sequestration. For example higher soil organic carbon levels were found in municipal solid waste compost amended soil when compared to bio-solids compost, fertilizer and control treatments in calcarous soil (Zinati *et al*., 2001). Returning organic wastes to the soil is a time-honored practice worldwide and is the key to many sustainable agricultural systems found even today. The ability of organic wastes to increase carbon sequestration in soil has been reported by Gibson *et al*., (2002). They reported that with annual additions of 35 t/ha of farm yard manure since 1852, soil carbon storage in the top soil has increased threefold and is still increasing in New South Wale. .

2.2 Carbon dynamics in soil and atmosphere

The carbon cycle (Fig.2.2) is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth (Forge, 2001). It is one of the most important cycles of the earth that allows carbon to be recycled and reused throughout the biosphere and all of its organisms. The major reservoirs of carbon are: the atmosphere, the terrestrial biosphere, which is usually defined to include fresh water systems and non-living organic material, such as soil carbon, the oceans, including dissolved inorganic carbon and living and non-living marine biota, the sediments including fossil fuels, and the earth's interior, carbon from the earth's mantle and crust is released to the atmosphere and hydrosphere by volcanoes and geothermal systems. The annual movements of carbon, the carbon exchanges between reservoirs, occur because of various chemical, physical, geological, and biological processes. The ocean contains the largest active pool of carbon near the surface of the earth, but the deep ocean part of this pool does not rapidly exchange with the atmosphere in the absence of an external influence, such as a black smoker or an uncontrolled deep-water oil well leak. IPCC, (1990) reported that the oceans contain about 39000 x 1015 g of C, the atmosphere contains about 750 g of C and terrestrial systems about 2200 g of carbon respectively. Although the soil vegetation carbon pool is small compared with that of the oceans, potentially it is much more labile in the short term. The carbon balance of the terrestrial ecosystems can be changed markedly by the direct impact of human activities – including deforestation, biomass burning , land use changes and environmental pollution – which release trace gases that enhance the green house effect (Intergovernmental Panel on Climate Change (IPCC), 1990, Trabalka and Reichle 1986).

The global carbon budget is the balance of the exchanges (incomes and losses) of carbon between the carbon reservoirs or between one specific loop (e.g., atmosphere ↔ biosphere) of the carbon cycle. An examination of the carbon budget of a pool or reservoir can provide information about whether the pool or reservoir is functioning as a source or sink for carbon dioxide. Carbon exists in the Earth's atmosphere primarily as the gas carbon dioxide (CO_2). Although it is a small percentage of the atmosphere (approximately 0.04% on a molar basis), it plays a vital role in supporting life. Other gases containing carbon in the atmosphere are methane and chlorofluorocarbons (the latter is entirely anthropogenic).

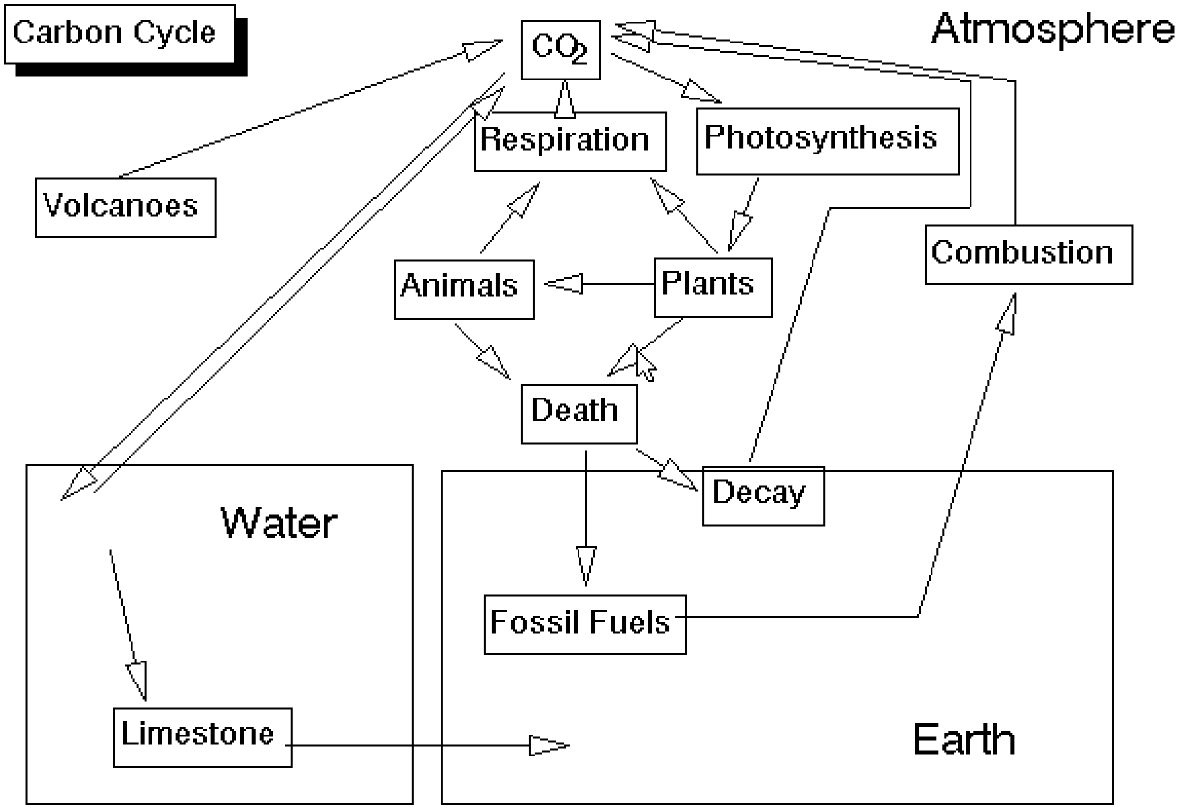


Fig. 2.2: Carbon cycle. (Source: Forge, 2001).

Trees convert carbon dioxide into carbohydrates during photosynthesis, releasing oxygen in the process. This process is most prolific in relatively new forests where tree growth is still rapid. The effect is strongest in deciduous forests during spring leafing out. This is visible as an annual signal in the Keeling curve of measured CO_2 concentration.

Generally, CO_2 in the atmosphere is absorbed by plants, which transform it into carbohydrates, cellulose and other sugars. Each plant uses some of the carbon compounds to meet its energy needs and converts them back into CO_2. Some of the carbon remaining in the plant is then removed from the system when the plant is harvested; the rest ends up in the ground and is transformed into CO_2 again by microbes in the soil. This cycle is identical in all crop systems, but the quantities of CO_2 involved vary depending on climate, soil and type of plant. The cycle is slightly more complex on farms where animals are raised because instead of being removed from the system, a considerable proportion of the plant matter is used as bedding or feed. Some of that carbon is released by the animals in the form of CO_2, some is removed in the form of animal products (meat, for example), and a significant quantity is returned to the ground in the form of manure. On land that has undergone few changes over the years (a natural prairie, for example, or land that has been farmed the same way for many decades), there is a balance between the carbon captured by the plants and the carbon returned to the atmosphere; as a result, the quantities of carbon stored in the soil do not change (Agriculture and Agric-food Canada Research Center, 1998). However, a change in land management disrupts the carbon cycle. For example, when forests and natural prairies are cleared for farming, a large quantity of the original organic matter is transformed into CO_2 and released into the atmosphere. When the land is then used for crops for several decades, the quantities stored in the soil become stable once again. However, when farming practices are changed to increase the organic carbon content of the soil, the reverse occurs: the soil captures more CO_2 than it emits, which means that CO_2 is removed from the atmosphere and stored in the soil - carbon sequestration. Figure 2.2 illustrates the changes that occur at various times in carbon cycle.

A range of land management strategies based on the intervention of higher plants and soil decomposition processes have been reviewed to enhance carbon pools in agricultural soils and mitigate climate change (Woodward *et al.*, 2009). These include: the adoption of no-tillage arable agriculture, which minimizes soil disturbance and the breakdown of crop residues; the conversion of arable land to grassland, which causes a build-up of organic matter at the soil surface; and the use of cover crops in rotations. The world is committed to understanding the factors that influence climate change, reducing uncertainties in assessments of climate change, and developing strategies to mitigate change. Atmospheric greenhouse gas (GHG) concentrations have been increasing for about 2 centuries, mostly as a result of human (anthropogenic) activities, and now are higher than they have been for over 400,000 years (Forge, 2001). As shown in the simplified representation of the global carbon cycle (Fig. 2.2), about 6 billion tons (gigatones) of carbon are released into the air by human activity each year, three-quarters from the burning of fossil fuels and the rest from deforestation and other changes in land use, with a small amount from cement production. In the last few decades the world has recognized that human induced carbon dioxide and other greenhouse gases keep the planet warmer than it should otherwise be (Woodward *et al*., 2009).

2.3 Soil carbon and climate change

Although the effects of increased levels of CO_2 on global climate are uncertain, many agree that a doubling of atmospheric CO_2 concentrations, predicted for the middle of this century by the Intergovernmental Panel on Climate Change (IPCC), could have a variety of serious environmental consequences. The causes of climate change lead to a build-up of gases generally referred to as greenhouse gases (GHGs), which include carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), sulphur dioxide (SO_2), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (Sf6) (Akamigbo, 2010a). These gases absorb the terrestrial radiations from the earth re-radiate the heat back to the earth, thereby leading to a general increase in temperature often referred to as global warming (Ozor, 2009).

There is presently much concern that climate change will enhance the decomposition of soil carbon, potentially shifting soils from being sinks to sources of carbon dioxide and thereby accelerating climate change (Powlson *et al*., 2011). At the same time, there is also much debate about the possibility to increase the amount of carbon sequestered in soil, and hence mitigate climate change. Recent studies reveal that both the loss and gain of soil carbon are strongly regulated by plant-microbial-soil interactions (Ann-Katrine**,** 2011). Climate change can impact on soil carbon in many ways, both direct and indirect. For direct effects, one of the most commonly discussed ideas is that global warming will accelerate rates of heterotrophic microbial activity, thereby increasing the transfer of carbon dioxide from soil to the atmosphere, thus creating a positive feedback on climate change. Although it is well known that temperature is an important determinant of rates of organic matter decomposition, the nature of the relationship between temperature and heterotrophic respiration, and its potential to feedback to climate change are far from clear (Davidson and Janssens, 2006). Recent studies also reveal the potential for strong indirect effects of climate change on soil carbon cycling, i.e. responses mediated via plants (Ann-Katrine**,** 2011). Several mechanisms occur here which can broadly be divided into two: first, as mentioned above, rising atmospheric concentrations of carbon dioxide indirectly impact on soil microbes via increased plant photosynthesis and transfer of photosynthetic carbon to soil; and, second, long-term climate change-induced changes in vegetation composition alter the amount and quality of organic matter entering soil, and other soil properties, thereby affecting the below ground decomposer food web. Recent studies show that both of these mechanisms can have significant consequences for the carbon budget of terrestrial ecosystems under climate change (Bardgett, 2011).

The concentration of carbon dioxide (CO_2) in the atmosphere increased from 285 ppm at the end of the nineteenth century, before the industrial revolution, to about 366 ppm in 1998 (equivalent to a 28 percent increased as a consequence of anthropogenic emissions of about 405 gigatones of carbon into the atmosphere (IPCC, 2000). This increase was as the result of fossil-fuel combustion and cement production (67%) and land use change (33%). Acting as carbon sinks, the marine and terrestrial ecosystems have absorbed 60% of these emissions while the remaining 40% has resulted in the observed increase in atmospheric CO_2 concentration. According to the Inter-Governmental Panel on Climate Change (IPCC, 2000), land use change and soil degradation are major processes for the release of CO_2 to the atmosphere. The hazards of climate change are many and serious. The concerns raised by these hazards have led to the 1997 international agreement in Kyoto (Kyoto Protocol), whereby most countries are committed to reducing their GHG emissions to the atmosphere. This protocol included new strategies and policies for implementation of agriculture and forestry management practices that enhance carbon sequestration both in biomass and soils. These activities are included in the Articles 3.3 and 3.4 of the Kyoto protocol and are known as “land use, land use change and forestry (IPCC, 2000). Other practices can be used to reduce agricultural greenhouse gas emissions: for example, replacing a portion of mineral nitrogen fertilizer with legume cover reduces the indirect CO_2

emissions attributable to fertilizer production (Robertson *et al.*, 2000). Farmers will therefore have to include soil sinks in a broader strategy aimed at reducing their greenhouse gas emissions. The importance of these activities is that any action taken to sequester C in biomass and soils will generally increase the organic carbon content of soils, which in turn will have a positive impact on environmental, agricultural and biodiversity aspects of ecosystems. The consequences of an increase in soil carbon storage can include increase in soil fertility, and productivity for food production and security, and prevention of land degradation.

2.4 Carbon forms and sequestration in soil

Soil carbon is a key component of any terrestrial ecosystems, and any variation in its abundance and composition has important effects on many of the processes that occur within the systems. Nonetheless, the size and dynamics of carbon pools in the soils of the world are still poorly known (Intergovernmental Panel on Climate Change, 1990; Legros *et al*., 1994). There are five global carbon pools, of which the soil is the third largest after the oceanic and the geological pools. Globally, soils contain 2500 billion tons of carbon, and together with vegetation, hold 2.7 times more carbon than the atmosphere. Powlson *et al*. (2011) reveal that current best estimates claim that worldwide, soils store 684-720 picogram (Pg) of C within the upper 30 cm, and 1462-1548 picogram (Pg) of carbon to a depth of 1m. (1Pg = 1×10ˆ15 gram). The upper 30cm of the soil profile to 1m clearly stores a disproportionate amount of C; these ecologists know to be the zones where continuous inputs from roots and organic matter replenish carbon. To put these numbers in an ecosystem context, the amount of C stored globally in soils to 30cm is twice the amount of C stored as CO_2 in the atmosphere and three times the amount of C stored in above ground vegetation (Powlson *et al.,* 2011). Clearly, soils represent a huge pool in global C budgets and should be managed with the knowledge that changes may represent a powerful feedback on the global C cycle. This vast storage potential is what has popularized the idea of sequestering even more C in soils and has spurred a myriad of different research approaches, from ecosystem-scale reforestation efforts to molecular studies of C-mineral binding interactions.

Most soil carbon is in the form of soil organic matter which is mostly found at the soil surface. This organic matter is made up of dead plant and animal material at various stages of decomposition, substances synthesized by microbes and/or chemically from the breakdown products of decomposition, and living microorganisms and animals (FAO, 2005). Soils also contain inorganic carbon in the form of elemental carbon and carbonate minerals, such as calcite, dolomite and gypsum. Soils vary tremendously in the amount of carbon they contain, with soil organic carbon contents varying due to a variety of factors such as vegetation type, climate, parent material, drainage, and the activity and diversity of soil biota. In general, however, the amount of carbon in soil is determined by the balance between carbon input from plant growth, in the form of dead plant litter (roots and shoots) and root exudates, and output via decomposition processes, burning and soil erosion. Hence, any factor that limits the amount of organic matter entering soil, such as a decline in plant productivity, or its breakdown in soil by the soil food web, will cause a build-up of organic matter in soil.

Generally, soil carbon can be grouped into three major forms namely, total, inorganic and organic carbon. According to Wang *et al*., (2008) better understanding of the dynamics of soil carbon is important for refining agricultural management practices and for improving sustainable land use. The soil is the largest terrestrial pool of organic carbon with global estimates ranging from 115 to 2200 pg (or g) of carbon (Batjes, 1992), 1576 pg of carbon (Eswaran *et al.*, 1993) and 1220 picogram of carbon (Sombroek *et al*., 1993) respectively. SOC is an active pool containing roughly twice as much carbon as the atmosphere and 2.5 times as bio-data. According to Batjes, (1996), soil organic carbon is estimated to be 684 – 724 picogram in upper 100cm, and 2376 – 2456 picogram in the upper 200cm. Most methods for determining soil organic carbon do not account for resistant forms such as charcoal (Skjemstad *et al*., 1990); thus, it remains difficult to quantify this source of organic carbon in global budgets. Inorganic carbon in the soil occurs largely in carbonate minerals such as calcium carbonate ($CaCO_3$) and dolomite ($MgCO_3$). Some types of soil, particularly the acid and strongly weathered ones, do not contain appreciable amounts of inorganic carbon because the carbonates originally present in the parent material have been dissolved. Large carbonate concentrations are common in the soil of dry areas, as well as in soils formed over calcareous parent materials such as the rendzinas and some lithosols. Reserves of inorganic carbon (as carbonate) stored in soils have been estimated to be 780 – 930 pg (Schlesinger, 1990), and 720 pg of carbon (Sombroek *et al*., 1993).

Total carbon in soil consists of organic and inorganic carbon, and is the largest fraction of carbon in soil. According to Batjes (1996), total soil carbon pools for the entire land area of the world, excluding carbon held in the litter layer and charcoal amounts to 2157 – 2293 pg in the upper 100cm. although deforestation, changes in land use and predicted climate change can alter the amount of carbon held in the superficial soil layers rapidly.

2.4.1 Soil organic carbon (SOC)

Soil organic carbon refers to the carbon present in soil organic matter. The latter is the heterogeneous mixture of substances present in soils representing the products at all stages of decomposition of plants, animals and microbes. According to Zhang and Grath, (2004), soil organic carbon is the organic component of terrestrial system, having both internal and external exchanges with the atmosphere and the biosphere. However, SOC is any material produced originally by living organisms that is returned to the soil and goes through a decomposition process. At any given time it consists of a range of materials from the intact original tissues of plant and animals to the substantially decomposed mixture of materials known as humus. Formation of soil organic carbon from plants and animal residues is a complex phenomenon that includes the decomposition, humification, accumulation and distribution of the various organic substances within the soil profile (Gibson *et al*., 2002). SOC is made up of a continuum of soil organic compounds in terms of the ease of their decomposition and turnover time. With successive decomposition, the more easily decomposed substances are lost to the atmosphere as CO_2, and the remaining compounds are further transformed chemically and biologically (the process of humification). The soil organic carbon present in the soil at any time consists of a complex mixture of organic compounds representing products at different stages of decomposition and only a portion of the input organic material is eventually converted to the stable form of soil organic carbon commonly known as humus (Gibson *et al*., 2002).

The elemental composition of soil organic matter consists of about 50% carbon with lesser amounts of oxygen (O) and hydrogen (H) plus small quantities of nitrogen (N), phosphorus (P), sulphur (S) and many other elements. Soil organic matter is a fundamental component of the soil that controls the chemical, physical and biological aspects of soil quality (Chan, 2001). In recent years, considerable interest has been generated in assessment of the physical, chemical and biological quality of agricultural soils (Haynes *et al*., 2003). Healthy soil is the foundation of food system that produces healthy crops. Plants obtain nutrients from two natural sources: organic matter and minerals. The amount of SOC that exists in any given soil is determined by the balance between the rates of organic carbon input (vegetation) and output (CO_2 from microbial decomposition). However, soil type, climate, management, mineral composition, topography, soil biota and the interactions between each of these are modifying factors that will affect the total amount of soil organic carbon in a profile as well as the distribution of SOC content with depth. It is important to note that any changes made to the natural status of the soil system (conversion to agriculture, deforestation, plantation) will result in different conditions under which soil organic matter enters and exits the system.

Forms and classification of soil organic matter have been described by Tate, (1987) and Theng, (1987). SOM occurs in various fractions varying in degree of decomposition, recalcitrance and turnover rate (Schimel *et al.*,1985). Parton *et al.*, 1987 divided soil organic carbon into active, slow and passive pools with different turnover times (15 – 1000 years). For practical purposes, SOM may be divided into above ground and below ground fractions. Above ground organic matter comprises plant residues and animal residues; below ground organic matter consists of living soil fauna and micro flora, partially decomposed plant and animal residues and humic substance (FAO, 2005). Conventionally, organic matter is fractionated into fulvic acids, humic acids and humin or into sephadex particle size fractions (Onweremadu *et al.*, 2008b). Although soil organic matter can be partitioned conveniently into different fractions, these do not represent static end product. Instead the amount present reflects a dynamic equilibrium. The total amount of partitioning organic matter in the soil is influenced by soil properties and by the quantity of annual inputs of plant and animal residues to the ecosystem. For instance, in a given soil ecosystem, the rate of decomposition and accumulation of soil organic matter is determined by such soil properties as texture, pH, temperature, moisture, aeration, clay mineralogy and soil biological activities.

Soil organic carbon levels exhibit variability as a result of dynamic interactions between parent material, climate and geological history, on regional and continental scale (Wang *et al.*, 2001). However, land use and landscape attributes including slope, aspect and elevation may be the dominant factors impacting SOC content in areas with homogenous parent material and a single climate regime (Rezaei and Gilkes, 2005). The SOC content in continuous cultivated land is also strongly dependent upon crop and soil management practices, such as crop species and rotation, tillage methods, fertilizer rate, manure application, pesticide use, irrigation and drainage, and soil and water conservation (Heenan *et al*., 2004). All these practices control the SOC inputs from crop residues and the addition of organic amendments and the SOC outputs through decomposition into gases and transportation into aquatic ecosystems via leaching, runoff and erosion (Turner and Lambert, 2000). Traditionally, soil aggregation has been linked with either total C (Matson *et al*., 1997), or organic C levels (Dala and Mayer, 1986). More recently, techniques have developed to fractionate C on the bases of lability (ease of oxidation), recognizing that these sub-pools of C may have greater effects on soil physical stability and be more sensitive indicators than total C values of C dynamics in agricultural systems (Blair and Crocker, 2000, Blair *et al*., 1995). The labile C fraction have been shown to be an indicator of key soil chemical and physical properties. For example, this fraction has been shown to be the primary factor controlling aggregate breakdown in ferrosols (*non* cracking red clays) measured by the percentage of aggregates measuring less than 0.125 mm in the surface crust after simulated rain in the laboratory (Bell *et al*., 1999). The resistant or stable fraction of SOC decomposes very slowly, and therefore has less influence on soil fertility than the active organic fraction.

2.4.2 Effects of soil organic carbon on soil properties

Soil organic carbon is considered the most important of soil quality (Gregorich *et al*., 1994). SOC influences soil chemical, physical and biological properties that control nutrient cycling and consequently have major effects on soil productivity. In particular, the suitability of soil for sustaining plant growth and biological activity is a function of soil physical (porosity, tilth and water holding capacity) and chemical (nutrient supply capability, pH and salt content) properties, many of which are function of soil organic matter. The Soil organic carbon is key resource owing to its ameliorative effect on nutrient supply, detoxification of harmful soil constituents, moisture and nutrient retention as well as structure formation (Woomer and Mychena, 1993). Due to the significant role of SOC in nutrient cycling, there has long been an interest in understanding how management practices affect soil C pools (Johnson and Curtis, 2001).

2.4.2.1. Increased soil moisture and infiltration rate

Organic matter influences the physical conditions of the soil in several ways. Plant residues that cover the soil surface protect the soil from sealing and crusting by raindrop impact thereby enhancing rain water infiltration and reducing runoff. Surface infiltration depends on a number of factors including aggregation and stability, pore continuity and stability, the existence of cracks and the soil surface condition (FAO, 2005). Increased SOC contributes indirectly to soil porosity (via increase soil fauna activity). Fresh organic matter stimulates the activity of macro fauna such as earthworms which create burrows lined with the glue-like secretions from their bodies and intermittently filled with worm cast materials. According to Michel *et al*., (2010), SOC is known to reduce the impact of raindrops on soil surface, improve soil porosity and water infiltration. Increased level of SOC and associated soil fauna lead to greater pore space with the immediate result that water infiltrates more readily and can be held in the soil (Roth, 1985). The improved pore space is the consequence of the bioturbating activity of earthworms and other organisms and channels left in the soil by decayed plant roots. According to FAO (2005), organic carbon intimately mixed with mineral soil materials has a considerable influence in increasing moisture holding capacity especially in the top soil, where the organic matter content is greater.

2.4.2.2. Reduced bulk density and increased aggregate stability

Soil organic carbon is a major determinant of the structural stability of tropical soils. Organic matter contributes to stability of soil aggregate through the bonding or adhesion properties of organic materials, such as bacterial waste products, organic gels, fungi hyphae and worm secretions and casts. FAO, (2005) reported that at SOC < 2%, soil aggregates were considered unstable, moderately stable at 2-2.5% and very stable at SOC content > 2.5%. The quality of crop residues, in particular their chemical composition, determines their effects on soil structure and aggregation (FAO, 2005). Blair *et al*., (2003) reported a rapid breakdown of *Medicago truncatula* (Medic) and *Oryzae sativa* (rice) straw residues resulting in a rapid increase in soil aggregate stability through the release of many soil-binding components. As organic materials undergo further breakdown they will be lost from the system resulting in a decline in soil aggregate stability over time. The slow release of soil binding agents from organic matter resulted in a slower but more sustained increase in the stability of soil aggregates. This indicates that continual release of soil-binding compounds from organic materials is necessary for continual increase in soil aggregate stability. According to Akamigbo, (1999a), low soil organic matter was responsible for increased bulk density and reduced porosity in cultivated soils of southeastern Nigeria. Organic matter facilitates aggregation which enhances macro pore formation, reduced micro pore (< 2 mm) surface area and enhances infiltration (Gale *et al.*, (2000)., Kaiser and Guggenberger, 2003), Generally, soil aggregation is caused primarily by polysaccharide production in situations where residues have low N content (Elliot and Lynch, 1984), an increase in soil C content leads to a 134% increase in aggregates of more than 2 mm and a 38% decrease in aggregates of less than 0.25 mm (Castro *et al.*, 1998). The active fraction of SOC is the primary factor controlling aggregates break down (Bell *et al.*, 1999).

2.4.2.3 Nutrient release and improvement in Soil biological properties

Soil organic matter is of great importance in low input agriculture. Sustained soil productivity is likely a function of efficient nutrient cycling where soil organic matter plays a great role (Onweremadu *et al.*, 2008a). In an undisturbed ecosystem, there is a closed organic matter cycle, meaning that nutrients and other fertility components stay on site and losses are minimal and compensated by nutrients added through decomposition of fresh organic materials. As soil organic matter is derived mainly from plant organic residues, it contains all of the essential plant nutrients; thus, accumulated organic matter is the store house of plant nutrients. Organic matter releases many plant nutrients as it is broken down in the soil, including nitrogen (N), phosphorus (P) and sulphur (S). Calegari and Alexander, (1998) reported that the P content (both inorganic and total P) of the surface layer (0-10cm) was high in plots with high organic matter. According to Onweremadu *et al.*, (2008b), available P and total sulphur are returned to the soil system through SOM mineralization. They further reported a significant positive correlation between SOM, available P and total sulphur. Organic matter releases nutrients in available forms via decomposition. In order to maintain this nutrient cycling system, the rate of organic matter addition from crop residues, manure and any other sources must be equal to the rate of decomposition, and take into account the rate of uptake by plants and losses by leaching and erosion (FAO, 2005). Where the rate of addition is less than the rate of decomposition, soil organic matter declines. Conversely, where the rate of addition is higher than the rate of decomposition, soil organic matter increases. The term steady state describes the condition where the rate of addition is equal to the rate of decomposition.

The stable fraction of SOM contributes mainly to soil colour and nutrient holding capacity of the soil. Organic matter provides nearly all of the CEC and pH buffering in soils low in clay or containing clays with low CEC. Cation exchange capacity determines the soils capacity to hold and exchange natural and artificial sources of cationic plant nutrients (Tisdale *et al*., 1985, Raji, 2011). In comparing conventional and conservation tillage, the highest values of soil CEC and exchangeable calcium (Ca) and magnesium (Mg) were found in legume-based rotation systems with the highest organic matter content (FAO, 2005). However, SOM stimulates nutrient release and uptake, beneficial soil life and increases soil pH. Wang *et al*., (2008) reported increase in soil total N, pH, CEC, available P and percentage base saturation as consequences of increased soil organic matter indicating the significant role of soil organic matter in soil quality enhancement.

Soil micro-organisms are of importance for plant nutrition as they interact directly in the bio-geochemical cycles of the nutrients. Increased production of green manure or crop biomass above ground and below ground increases the food source for the microbial population in the soil. Organic residues of appropriate quality and quantity act not only as sources of nutrients and organic matter but also may increase the size, biodiversity and activity of the microbial populations in soil. Diverse population of soil bacteria, fungi, protozoa and algae play a crucial role in soil quality and sustainability (Shrewood and Uphoff, 2000). They exploit a wide range of carbon substrate and are responsible for the decomposition of organic materials, thus transforming, releasing and cycling nutrients and essential elements such as carbon, nitrogen and phosphorus from complex organic forms (Stirling, 2001). The organic polymers in humified organic fractions of microbiologically decomposed organic matter act as binding agents for soil aggregate formation (Martens, 2000), an important determinant for good soil structure. Microbes can also benefit soil aggregation more directly either physically by fungal hyphal linkages or chemically by the production of polysaccharides that act as soil binding agents.

Agricultural production systems in which residues are left on the soil surface and roots left in the soil stimulate the development and activity of soil micro-organisms (FAO, 2005). In undisturbed ecosystems, nutrient recycling is enhanced by beneficial microbial associations such as mycorrhizal fungi, rhzobium, and azzoliculture. Another consequence of increased organic matter is an increase in the earthworm population. Earthworms rarely come to soil surface due to their characteristics: photophobia, lack of pigmentation and tolerance to periods of submergence and anaerobic conditions during rainfall. Soil moisture is one of the most important factors that determine the presence of earthworms in the soil. Through cover crops and crop residues, evaporation is reduced and organic matter in the soil is increased, which in turn can hold more water. Residues on the soil surface induce earthworms to come to the surface in order to incorporate the residues in the soil. The burrowing activity of earthworms creates channels for air and water; this has an important effect on oxygen diffusion in the root zone, and the drainage of water from it. Furthermore, nutrients and amendments can be distributed easily and the root system can develop, especially in acid soil in the existing casts. Earthworms create numerous channel in the topsoil, which increases overall porosity, and infiltration under very intense rainfall conditions.

2.4.3 Factors controlling soil organic matter levels in soil

Soil organic carbon levels are dependent on a number of factors. Some are inherent (cannot be changed easily) and others reflect management (Skjemsted, 2000, Dalal and Chan, 2001). The primary factors are temperature, rainfall, soil type and land use and management practices (including quantity and quality of inputs). Changes in soil organic carbon levels depend upon the relative rate at which organic materials are added to and lost from the soil. In natural ecosystems, rainfall and temperature are the main factors determining plant biomass production and subsequent decomposition to soil organic carbon for a given soil type. These factors determine the equilibrium soil organic carbon levels at a particular location. Equilibrium soil organic carbon levels are reached when additions of organic carbon equal the losses. Generally, the soil organic carbon level is highest in the surface layer and then declines with depth. However, distribution of soil organic carbon with depth tends to vary with different soil type. For instance, the decline of soil organic carbon with depth is relatively slow in black earth compared to Krasnozems (Spain *et al*., 1983). Furthermore, the vertical distribution of soil organic carbon varies with vegetation type. For example, the percentage of soil organic carbon in the top 20cm (relative to the first meter) averaged 33%, 42% and 50% for shrub lands, grassland and forest respectively (Jobbagy and Jackson, 2000). In agricultural systems (or other modified ecosystems) soil organic carbon turnover rate and equilibrium levels are further impacted by human activities, namely land use and management practices. These include practices that modify levels of carbon inputs as well as those that accelerate carbon losses.

Rainfall and temperature affect both input and losses of organic materials in soil ecosystem. As such, they control the boundaries for maximum carbon sequestration in soils in a given area (Australian Greenhouse Office, 2000). Rainfall plays important roles in soil organic carbon levels because of its effects on plant productivity. Dalal and Mayer (1986) reported an increase in organic carbon in virgin soils of 48kg C/ha for each mm of rainfall. Temperature has a direct effect on the rate of decomposition of organic materials for soil organic carbon (Jenkinson, 1991). The decomposition of soil organic matter is more rapid in tropical region than in more temperate region (Dalal and Chan, 2001). The equilibrium soil organic carbon level tends to vary amongst soil types. This is illustrated on a world scale by Eswaran *et al.*, 1993 who reported that Histosols contain about 205 t/ha organic carbon, Vertisols contain 6 t/ha organic carbon and Ultisols contain 9 t/ha organic carbon. Considerable variation exists in the soil organic carbon level within a specific soil type (Spain *et al*., 1983). Such variations in soil organic carbon levels are related to differences in management, climate, parent material, soil mineral composition, soil biota, topography and the frequency of various catastrophic natural or human induced events (fire, flooding, erosion) (Baldock and Skjemsted, 1999).

Soil types affect soil organic carbon level through their composition (texture). Soil texture influences the mineralization of nitrogen pools (Chae and Tabatabai, 1986) and the net mineralization of soil organic matter and decomposition of plant material are more rapid in sandy soil than in clay soil. The lower net mineralization of soil organic carbon in clayey soil is linked to greater physical protection against microbial biomass attack (Hassink, 1992). Chan *et al* .,(1998) reviewed soil organic carbon dynamics on lighter-textured soils (defined as the surface horizon less than 30 – 35% clay content). The majority of soils under cultivation have typical soil organic carbon levels approaching 1%, and this was attributed to the low clay content and thus the lack of physical protection of the soil organic carbon.

Soil organic carbon levels in virgin soils decline rapidly once cultivation commences. This occurs because of the reduced carbon inputs into the soil system and the increased decomposition of plant residues and soil organic carbon under cropping regimes. In southeastern

Nigeria, as well as in many other parts of the world, soil organic carbon found in the cultivated soils are significantly lower than the corresponding soils found under natural vegetation (Ahukaemere, *et al*., 2012, Akamigbo, 1999a). Globally, grassland and forest soil tends to lose 20 – 50% of the original soil organic carbon content after 40 -50 years of land use change (Swift, 2001, Bruce *et al*., 1999). Several specific management practices have contributed to the loss of soil organic carbon observed under cropping. For example, Dalal and Mayer, (1986) reported an increase in soil organic carbon of 48kg C/ha/mm of rainfall in virgin soils compared with only 29kg C/ha/mm of rainfall in cultivated soils. Conventional cropping systems are characterized by burning of stubble and repeated tillage operation. Tillage not only increases soil aeration but also increases the direct contact of soil microbes with crop residues and soil carbon materials, both leading to increased rate of decomposition (Skjemstad *et al*., 2001). The exact impact of tillage on soil organic carbon is dependent on the intensity and type of tillage operation as well as soil type (Chan and Partley, 1998). Inappropriate or excessive tillage can lead to direct loss of soil organic carbon because of accelerated erosion. Soil degradation caused by these practices can also indirectly lead to soil organic carbon decline because of reduced crop yield (and thus reduced organic material input to the soil as crop residues). Similarly, burning of crop residues promotes a decline in soil organic carbon levels.

2.4.4 Components of organic matter; significance and function

Humus

Humus or humified organic matter is the remaining part of organic matter that has been used and transformed by many different soil organisms. It is a relatively stable component formed by humic substances, including humic acids, fulvic acids, hymatomelanic acids and humins (Tan, 1994). It is probably the most widely distributed organic carbon-containing material in terrestrial and aquatic environments. Humus cannot be decomposed readily because of its intimate interactions with soil mineral phases and is chemically too complex to be used by most organisms. One of the most striking characteristics of humic substances is their ability to interact with metal ions, oxides, hydroxides, mineral and organic compounds, including toxic pollutants, to form water-soluble and water-insoluble complexes (FAO, 2005). Through the formation of these complexes, humic substances can dissolve, mobilize and transport metals and organics in soils and waters, or accumulate in certain soil horizons. This influences nutrient availability, especially those nutrients present at micro concentrations only (Schnitzer, 1982). Accumulation of such complexes can contribute to a reduction of toxicity eg. aluminum (Al) in acid soils (Tan and Binger, 1986), or the capture of pollutants – herbicides such as Atrazine or pesticides such as Tefluthrin – in the cavities of the humic substances (Vermeer, 1996). About 35-55% of the non living part of organic matter is humus. It is an important buffer, reducing fluctuations in soil acidity and nutrient availability. Compared with simple organic molecules, humic substances are very complex and large, with high molecular weights. The characteristics of the well-decomposed part of the organic matter, the humus, are very different from those of simple organic molecules. Humus consists of different humic substances:

Humins

Humins are the fractions of humus that are not soluble in water at any pH and cannot be extracted even with a strong base like sodium hydroxide (NaOH). According to Pettit (2012), humins are those fractions of humic substances which are not soluble in alkali (high pH) and are not soluble in acid (low pH). He further stated that humin complexes are considered macro-organic substances because their molecular weights range from approximately 100,000 to 10,000,000. Humins present within the soil are the most resistant to decomposition (slow to breakdown) of all the humic substances (Pettit, 2012). According to FAO, (2005), the main functions of humins within the soil are to improve the soils water holding capacity, improve soil structure, maintain soil stability, to function as a cation exchange system, and to generally improve soil fertility. Because of these important functions, humin is the key component of fertile soils.

Humic Acids

Humic acids comprise a mixture of weak aliphatic (carbon chains) and aromatic (carbon rings) organic acids which are not soluble in water under acid conditions but are soluble in water under alkaline conditions (FAO,2005). They consist of that fraction of humic substances that are precipitated from aqueous solution when the pH is decreased below 2. Humic acids are termed poly-disperse because of their variable chemical features. On the average, 35% of the humic acid molecules are aromatic, while the remaining compounds are in the form of aliphatic molecules. The molecular size of humic acids range approximately from 10,000 to 100,000. Humic acid polymers readily bind clay minerals to form stable organic-clay complexes. According to Tan (2003)., Kurkova *et al*., (2004), the elemental composition of humic acids shows that the major element in their composition are carbon (C) , hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S). Analysis of extract of naturally occurring humic acids will reveal the presence of over 60 different mineral elements present, these trace elements are bound in humic acids molecules in a form that can be readily utilized by various living organisms (Pettit, 2012). As a result humic acids function as important ion exchange and metal complexing (chelating) systems. However, humic acids, one of the most important components of humic substance, help break up clay and compacted soils, assist in transferring micronutrients from soil to plants, enhance water retention, increase seed germination rates and stimulate the development of micro-flora populations in soil (Pena-Mendez *et al*., 2005). They further reviewed that humic acids also slow down water evaporation from soils-which is especially important in soils where clay is present at low concentration or not at all, in arid areas, and in sandy soils without the capability to hold water.

Fulvic Acids

Fulvic acid is a mixture of weak aliphatic and aromatic organic acids which is soluble in water at all pH conditions. The composition and shape of fulvic acid are quite variable, with molecular weights which range from approximately 1000 to 10,000. Fulvic acids have high oxygen content and many carboxyl (-COOH) and hydroxyl (-COH) groups, thus fulvic acids are more chemically reactive (Pettit, 2012). Fulvic acids have high exchange capacity which is as a result of the total number of carboxyl groups present. The number of carboxyl groups present in fulvic acids ranges from 520 to 1120 cmol(H^+)/kg. Like the humic acids, fulvic acids consist majorly of C, H, O, N, and S. among the humic substances, water soluble fulvic acids are especially important because of their abundance, mobility and ability to complex or chelate metal ions and interact with silica (William, 2008). It has been demonstrated that these interactions may increase the concentrations of metal ions and silica found in water solutions to levels that are far in excess of their assumed dissolution ability. Fulvic acid can bring into soil solution substantial amounts of potassium, aluminum, iron, magnesium and silicon from micas. From the biological standpoint, the metal chelating ability of fulvic acids is perhaps the most important factor in the growth cycle because it plays a vital role in the nutritional physiology of not only single cell algae, but also higher plant (William, 2008). Schnitzer, (1982) concluded that fulvic acid is a highly oxidized, biologically stable, water soluble, naturally occurring complexing agent that can complex divalent and trivalent metal ions and hydroxylated metal compounds that assist interaction with clay minerals.

Tartaric Acid

Tartaric acid which is common in soils and exudates of roots of cereals and solonaceous crops (Huang and Violante, 1986) is the most effective low molecular weight organic acid in inhibiting $Al(OH)_3$ crystallization; promoting the formation of non crystalline Al oxides (Violante and Violante 1980) and perturbing the formation of allophone and imogolite (Inoue and Huang, 1986). According to Violante and Huang (1985), high amount of tartaric acid in soil increases aggregation of soil particles. However, low concentration of tartaric ligands results to decreased specific surface and porosity due to insufficient perturbation of crystallization.

Non-humic substances: Significance and function

Non-humic organic molecules are released directly from cells of fresh residues, such as proteins, amino acids, sugars and starches. This part of soil organic matter is the active or easily decomposed fraction with great potential of boosting soil carbon sequestration. This active fraction is influenced strongly by weather conditions, moisture status of the soil, growth stage of the vegetation, addition of organic residues and cultural practices. It is the main food supply for various organisms in the soil. Carbohydrates occur in the soil in three main forms: free sugars in the soil solution, cellulose and hemicelluloses complex polysaccharides; and polymeric molecules of various sizes and shapes that are attached strongly to clay colloides and humic substances (Stevenson, 1994). The simple sugars, cellulose and hemicellulose, may constitute 5-25% of the organic matter in most soils, but are easily broken down by micro organisms (FAO, 2005). Polysaccharides promote better soil structure through their ability to bind inorganic soil particles into stable aggregates. Research indicates that the heavier polysaccharide molecules may be more important in promoting aggregate stability and water infiltration than the lighter molecules (Elliot and Lynch, 1984). Other soil properties affected by polysaccharides include CEC, anion retention and biological activity. The soil lipids form a very diverse group of materials, of which fats, waxes and resins make up 2-6% of soil organic matter.

2.5 Nitrogen behavior, roles and dynamics in soil.

Environmental and economic issues combined have increased the need to better understand the role, behavior and fate of nitrogen (N) in soil and crop production systems. Nitrogen is the nutrient most often deficient for crop production in most non-legumes cropping systems and its use can result in substantial economic return for farmers. Nitrogen in the soil is the most important element for plant development. It is required in large amounts and must be added to the soil to avoid a deficiency. Nitrogen is critically important to plants because it is a fundamental part of the chlorophyll molecule and is essential in the formation of amino acids and protein (Hodges, 2012). It is responsible for lush, vigorous growth and the development of a dense, attractive lawn. Although nitrogen is the most abundant element in our atmosphere, plants can not use it until it is naturally processed in the soil, or added as fertilizer. Plants obtain their N as inorganic nitrate and ammonium ions in the soil solution but N is not a natural constituent of rocks or minerals. Rather, the natural state of nitrogen is as nitrogen gas (N_2) in the atmosphere which occupies 78% of the air by volume. It is estimated that there are 31,250 tons of N over every acre on earth. The nitrogen gas (N_2) in the atmosphere is very non-reactive and not available to plant. An excess of nitrogen, caused by over application of fertilizer, can result in rapid, lush growth, delay initiation of flowering or fruiting and a diminished root system, resulting in low yields of some crops. In extreme cases too much quick released nitrogen can cause burning of the leaf tissue, and plant death. Excess nitrogen can also encourage tender, succulent plant growth that may be more susceptible to certain plant diseases (Halving *et al.*, 2005). As most plants take up nitrogen in the form of nitrate-nitrogen, its deficiency in soils is indicated by light green to yellow appearance of leaves, early shedding of leaves in fruit trees, death of lateral buds, poor set of fruits and shriveled kernels in cereals (Foth, 1984).

Nitrogen exists in the soil system in many forms and changes (transforms) very easily from one form to another (Leary *et al.,* 1994). The route that N follows in and out of the soil system is collectively called the "nitrogen cycle" **(**Fig.2. 3**)** and is biologically influenced. Biological processes, in turn, are influenced by prevailing climatic conditions along with the physical and chemical properties of a particular soil. The availability of nitrogen in the soils is determined by processes of nitrogen mineralization, nitrogen immobilization, denitrification and organic matter decomposition (Yano *et al*., 2000). Nitrogen, present or added to the soil, is subject to several changes (transformations) that dictate the availability of N to plants and influence the potential movement of NO_3^- in soil (Leary *et al*., 1994). Organic N that is present in soil organic matter, crop residues, and manure is converted to inorganic N through the process of mineralization . In this process, bacteria digest organic material and release ammonium (NH_4^+) nitrogen. Formation of NH_4^+ increases as microbial activity increases. Ammonium-N has properties that are of practical importance for N management. Ammonium has a positive charge and, therefore, is attracted or held by negatively charged soil and soil organic matter. This means that NH_4^+ does not move downward in soils and cannot be lost via leaching . Nitrogen in the ammonium form that is not taken up by plants is subject to other changes in the soil system. NH_4^+ -N is converted to NO_3^- -N through the process of nitrification. Although nitrification in soil could proceed within hours, NH_4^+ could also be electrostatically adsorbed to the cation exchange complex that might delay the microbial transformation processes (Hook, 1981). Nitrification is a biological process and proceeds rapidly in warm, moist, well-aerated soils. Nitrification slows at soil temperatures below 50^0F thus, the general recommendation is that ammoniacal (NH_4^+ forming) fertilizers should not be fall- applied until soils are below 50^0 F. Nitrate is a negatively charged ion and is not attracted to soil particles or soil organic matter like NH_4^+. Nitrate-N is water soluble and can move below the crop rooting zone under certain conditions, consequently, it is highly mobile and subject to leaching losses when both soil NO_3^- content and water movement are high (Halving *et al*., 2005). Nitrate-nitrogen (NO_3-N) is one of the essential anions in soils and crop production. In addition to this, NO_3-N is a critical factor in environmental quality especially as it affects groundwater quality. Nitrate-nitrogen is prone to leaching, thus a potential pollution hazard to surface and groundwater (Isirimah *et al*., 2003). Leaching can alter the distribution of NO_3^- which normally increases below the root zone.

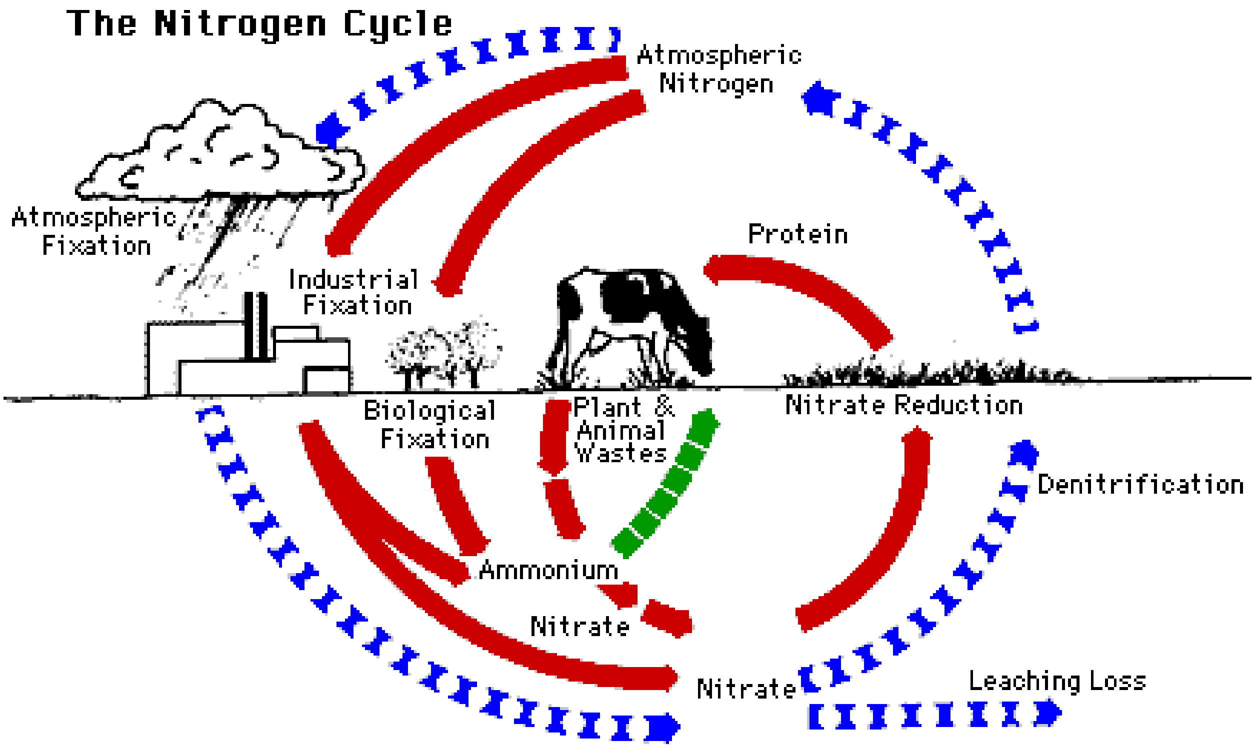


Figure 2.3. The Nitrogen Cycle.
Source: Leary *et al*., (1994).

Nitrate (NO_3^-) and (NH_4^+) are converted to N gases (unavailable form) that are lost to the atmosphere through denitrification by soil bacteria. Denitrifying bacteria use NO_3^- instead of oxygen in the metabolic processes. Denitrification takes place where there is waterlogged soil and where there is ample organic matter to provide energy for bacteria. For these reasons, denitrification is generally limited to topsoil. Denitrification can proceed rapidly when soils are warm and become saturated for 2 or 3 days.

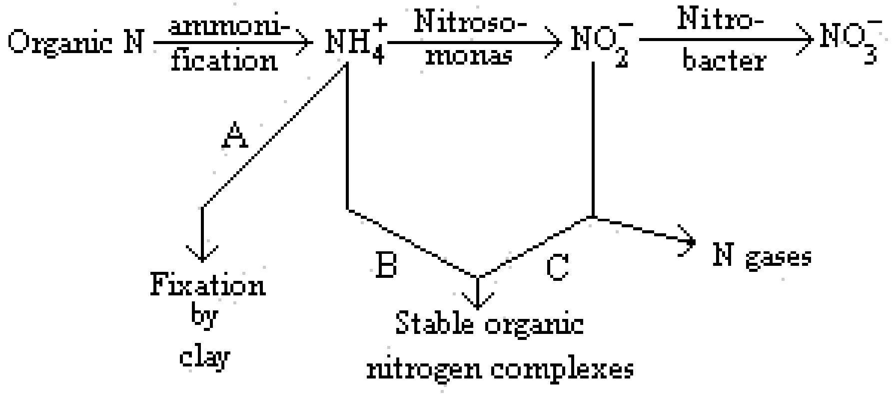
However, a temporary reduction in the amount of plant-available N can occur from immobilization (tie up) of soil N. Immobilization occurs when nitrate and/or ammonium present in the soil is used by the growing microbes to build proteins. The difference between microbial release of nitrogen (mineralization) and incorporation of nitrogen into biomass (immobilization) largely determines the amount of nitrogen available for plant uptake (Jansson and Persson 1982, Binkley and Hart 1989). The rate at which microbes immobilize nitrogen depends in part on the supply of available energy, or reduced carbon (Jansson and Persson, 1982). The actively growing bacteria that immobilize some soil N also break down soil organic matter to release available N during the growing season. There is often a net gain of N during the growing season because the additional N in the residue will be the net gain after immobilization-mineralization processes. The relative quantities of carbon and nitrogen (C:N ratio) in crop residues and other fresh organic materials, soil organic matter; and soil microorganisms affect mineralization and immobilization of nitrogen in soil. Whether nitrogen is mineralized or immobilized depends on the C:N ratio of the organic matter being decomposed by soil microorganisms. However, when organic residues with high C:N (> 20:1) ratio are added to soil, soil N is immobilized during the initial decomposition process. For residues with C:N < 20:1 there is a release of mineral nitrogen early in the decomposition process.

2.5.1 Chemical reaction of ammonia and nitrite with organic matter

The fate of mineral forms of N in soil is determined to some extent by non-biological reactions involving NH_4^+, NH_3 and NO_2^- as depicted in Fig 2.4. In addition to NH_4^+ fixation by clay minerals (reaction A), NH_3 and NO_2^- react chemically with organic matter to form stable organic N complexes (reactions B and C). The chemical interaction of NO_2^- with organic matter may lead to the generation of N gases. Although both types of reactions can proceed over a wide pH range, fixation of ammonia is favored by a high pH (>7.0). In contrast, NO_2^- -organic matter interactions occur most readily under highly acidic conditions (pH of 5.0 to 5.5 or below).

2.5.2 Sources of Nitrogen in soil

Nitrogen can be supplied to plants through both organic and inorganic sources. The ultimate source of all nitrogen used by plants is nitrogen gas (N_2) which constitutes 78% of the earth's atmosphere (Halving *et al* 2005). Hauk, (1984) revealed that the primary sources of nitrogen in the soil are the atmosphere, soil organic matter, commercial fertilizers, crop residues and animal wastes. Although unavailable to most plants, large amounts of N_2 can be used by leguminous plants via N fixation. In this biological process, nodule-forming *Rhizobium* bacteria inhabit the roots of leguminous plants and through a symbiotic relationship convert atmospheric N_2 to a form the plant can use. The amount of N fixed by legumes into usable N can be substantial, with a potential for several hundred lb N/acre/year to be fixed in an alfalfa crop. Any portion of a legume crop, that is left after harvest, including roots and nodules, supplies N to the soil system. When the plant material is decomposed, N is released. Several non-symbiotic organisms exist that fix N, but N additions from these organisms are quite low (1 - 5 lb/acre/year). In addition small amounts of N are added to soil from precipitation . Commercial N fertilizers are also derived from the atmospheric N pool. The major step is to combine N_2 with hydrogen (H_2) to form ammonia (NH_3). Anhydrous ammonia is then used as a starting point in the manufacture of other nitrogen fertilizers. Anhydrous ammonia or other N products derived from NH_3 can then supplement other N sources for crop nutrition. Nitrogen can also become available for plant use from organic N sources which must be converted to inorganic forms before they are available to plants.



Nonbiological transformations of NH_3 and NO_2^- in soil.
(Stevenson 1982)

Fig.2.4. Non-biological transformation of organic nitrogen to ammonium and nitrate in soil

Nitrogen is available to plants as either ammonium (NH_4^+) or nitrate (NO_3^-). Crop residues from non-leguminous plants contain N, but in relatively small amounts compared with legumes. Nitrogen exists in crop residues in complex organic forms and the residue must decay (a process that can take several years) before N is made available for plant use.

Soil organic matter is also a major source of N used by crops. Organic matter is composed primarily of rather stable material called humus that has collected over a long period of time. Easily decomposed portions of organic material disappear relatively quickly, leaving behind residues more resistant to decay. Soils contain approximately 2,000 pounds N in organic forms for each percent of organic matter (Leary *et al*., 1994). Decomposition of this portion of organic matter proceeds at a rather slow rate and releases about 20 lb N/acre/year for each percent of organic matter. Organic nitrogen sources such as treated municipal wastes, crop residues and animal manures are important sources of nitrogen in the soil agro-ecosystem. However, these sources must be converted to inorganic forms (ammonium (NH_4^+) and nitrate (NO_3^-) before they become available for plant uptake.

2.5.3 Nitrogen losses in soil

In addition to all the transformations of nitrogen in the soil, there is also a significant loss to the soil. Most of this loss is a result of a combination of nitrogen forms and environmental conditions. Nitrogen can be easily lost from an agricultural system by various pathways. Those pathways include volatilization, leaching and runoff, and crop removal. Volatilization, or the gaseous loss of ammonia, may occur under certain conditions with ammonium fertilizers. In situations where the soil is alkaline, or where limestone has recently been applied on acid soils, applications of ammonium sulphate, urea or ammonium nitrate may result in the transformation of the ammonium to ammonia which may be lost to the atmosphere (Iowa Soybean Association, 2008). This situation can be avoided by incorporating these fertilizers into the soil in the case of soils with alkaline pH, or waiting at least a month after limestone applications before applying the ammonium fertilizers. Urea pills are particularly prone to volatilization if left on the surface of any soil. This material should be banded into the soil to reduce volatilization losses. Irrigation immediately after the application of urea is very effective in reducing losses. Some studies indicated that under optimal conditions, if not properly incorporated into the soil, nitrogen losses could exceed 16% of the nitrogen contained in the urea (Halving *et al*., 2005, Hodges, 2012). Anhydrous ammonia is a gaseous form of nitrogen and is very prone to volatilization if handled improperly. This material must be applied into the soil at sufficient depth to prevent loss. Soil moisture is important, and the soil should be moist but not saturated. Sandy and low CEC soils need deeper application than finer textured soil types.

Leaching and runoff are other important sources of nitrogen loss. Leaching occurs when inorganic forms of nitrogen, particularly nitrite and nitrate are solubilized and carried with water through the soil profile or with surface waters. Nitrate leaching, a major pathway of N loss in humid climates and under irrigated cropping systems is influenced by intensity of cropping and crop N uptake, soil profile characteristics that affect percolation, time, rate, source and method of N fertilization, rainfall pattern and intensity (Halving *et al*., 2005). Apart from being economic loss to the farmer, these nitrites and nitrates are pollutants to ground water and surface water resources. Heavy, one-time applications of nitrogen fertilizers on sandy textured soils, over application of manures, improperly timed applications of nitrogen fertilizers, poorly designed or non-existent soil conservation measures and periods of exceptionally heavy rain are critical factors that contribute to nitrite and nitrate leaching or runoff (Hodges, 2012).

Crop removal is a very important, but often overlooked way that nitrogen is lost from the soil. Many crop materials contain 2 to 4% nitrogen on a dry weight basis. If these crop materials are exported from the farm in the form of grains, forages and vegetables, there is a net loss of nitrogen. However, if crop residues are saved and returned to the soil, some of the nitrogen will be recycled for future crops.

2.6 Carbon-nitrogen (C/N) ratio in soil

The cycle of nitrogen in the ecosystems can strongly influence the carbon cycle as nitrogen is often the limiting nutrient in the ecosystems. In addition, the uptake of carbon depends on nitrogen availability in plants both directly as part of the process of photosynthesis and indirectly by influencing the structure and size of the plant leaf development (Eliasson, 2007, Van Minnen, 2008). Carbon and nitrogen are two chemical elements in organic matter which are extremely important, especially in their relation or proportion to each other. This relationship is called the carbon-nitrogen ratio. For proper handling of organic matter, good idea about the significance of carbon-nitrogen ratio is very important. Carbon is important because it is an energy-producing factor, nitrogen, because it builds tissue. When organic matter decays, the carbon is dissipated more rapidly than the nitrogen thus bringing down the carbon-nitrogen ratio. Materials with high C/N ratio such as sawdust (400:1) are considered highly carbonaceous, and has a very low nitrogen content. If much of it is added into the soil, there would not be enough nitrogen - the food of micro organisms which aid in the function of decomposition. They would thus have to consume soil nitrogen and create a deficiency of nitrogen, thereby depressing the crop yield. FAO, (2005) reported that C/N ratio is used to indicate the type of materials and ease of decomposition; hard woody materials with high carbon-nitrogen ratio being more resilient than soft leafy materials with low carbon-nitrogen ratio. Generally, legumes contain high amount of nitrogen and have low C/N ratio, which is a highly desirable condition. There is a great difference between the carbon-nitrogen ratio of raw organic matter and that of humus. The nitrogen in a leaf for instance may be only 1%, but by the time it turns to humus the amount of nitrogen of that more or less refined substance would be about 5%. The average nitrogen content of practically all humus is about 5%, but in organic matter it fluctuates considerably (FAO, 2005). Native humus would be expected to have a lower C/N ratio than most un-decayed plant residues for the following reasons. The decay of organic residues by soil organisms leads to incorporation of part of the C into microbial tissue with the remainder being liberated as CO_2. As a general rule, about one-third of the applied C in fresh residues will remain in the soil after the first few months of decomposition. The decay process is accompanied by conversion of organic form of N to NH_3 and NO_3^- and soil microorganisms utilize part of this N for synthesis of new cells. The gradual transformation of plant raw material into stable organic matter (humus) leads to the establishment of reasonably consistent relationship between C and N. Other factors which may be involved in narrowing of the C/N ratio include chemical fixation of NH_3 or amines by lignin-like substances. With carbon however, a different condition exists, while decomposing organic matter loses large amounts of carbon as it turns to humus, the percentage of it to the total mass does not seem to go up or down considerably. There is always a narrowing down of the C/N ratio when organic matter decomposes. The content of carbon in humus does not vary much, it averages about 50-53%.

Because of the close connection between carbon and nitrogen, indices as the carbon-nitrogen ratio in the terrestrial systems are often used to indicate the fertility of the forest soil and changes of the index can indicate differences in the rates of litter decomposition (Van Minnen, 2008). Also, Johnson and Curtis, (2001) reported that the amounts and concentrations of carbon and nitrogen in soil organic matter are often used as indicators of soil fertility. According to Thomas and Asakawa, (1993), C/N ratio is a primary indication of how chemical composition will influence decomposition since chemical composition of residues also controls decay rate. The C/N ratio of virgin soils formed under grass vegetation is normally lower than soils formed under forest vegetation, and for the latter, the C/N ratio of the humus layers is usually higher than for the mineral soil proper. As a general rule it can be said that conditions which encourage decomposition of organic matter result in narrowing of the C/N ratio. The ratio nearly always narrows sharply with depth in the profile; for certain subsurface soils C/N ratios lower than 5 are not uncommon. For surface soils, and for the top layer of lake and marine sediments, the carbon-nitrogen ratio generally falls within well-defined limits, usually from about10 to 12. In most soils, the C/N ratio decreases with increasing depth, often attaining values less than 5.0.

2.7. Parent materials and their influences on soil properties

Parent material has been recognized as an important factor of soil formation since the earliest scientific consideration of soil (Jenny, 1980). The formation of soil in a region can occur within a certain period of time depending on the parent material, climate, topography and vegetation of the region (Dinc *et al*., 1987, Irmak *et al*., 2007). In the tropics, the severity of the climatic factors causes an intense weathering of the rocks and their consequent transformation into soils. According to Gray and Murphy, (2002), parent material is considered to provide the primary raw material upon which the other influencing factors will serve to modify. Generally, parent material can be classified into: residium (material that formed from rock weathered in place), lacustrine (material that is moved by water and deposited in fresh water lakes), alluvium (material deposited on flood plains of active streams), alluvial fans, colluviums (material moved by gravity and deposited at the base of steep slopes), marine deposit (coastal plain sediments), organic deposits (organic materials).

Different parent materials affect the mineralogy, chemistry and morphology of soils under the same conditions such as topography and vegetation, especially in the tropics. Differences in physical, chemical and mineralogical properties of soils are related primarily to parent material (Irmak *et al*., 2007). According to Gray and Murphy (2002), parent material is a major source of most nutrients necessary for plant growth, with the notable exceptions of oxygen, hydrogen, nitrogen and carbon, which are primarily derived from the atmosphere and organic material. They further reviewed that the ability of soil to retain nutrients as indicated by its cation exchange capacity (CEC), and the type and amount of clay present in soil are influenced by parent material. Clays produced from mafic parent material such as montmorillonite and vermiculite, have higher CEC (activity) than those produced from siliceous parent material such as illite and kaolinite (Gray and Murphy, 2002). The parent material largely controls the potential quantity of clay resistant minerals such as quartz and their grain size, and the activity of clay produced. Argillaceous rocks such as shale are predominantly composed of clay particles, thus they give rise to soils with high amounts of clay.

However, the significant influence of parent material on soil texture has been reviewed (Gray and Murphy, 2002, Akamigbo and Asadu, 1983). The coarser the grain size of the parent material (e.g. quartz) the coarser the particle size of the soil, especially of the surface soil. The pH, erodibility and sodium (sodicity) content of soil is influenced by the parent material from which the soil is formed. The ratio of sodium relative to other exchangeable bases increases with increasing siliceous character of parent material. Highly siliceous parent material gives rise to soils that are very susceptible to external sources of sodium because of their inherently low base content (Hallsworth and Waring, 1964). Furthermore, soils derived from highly siliceous sandstones and granites are generally acidic than those derived from balsalts and andesites. Where carbonate is present in the soil, as is common over calcareous parent materials, soils will usually be slightly or even strongly alkaline in character. The susceptibility of soil to erosion (erodibility) is influenced by parent material (Onweremadu *et al*., 2007b). They further stated that soils with high levels of fine sand, silt and low clay levels are highly erodible. The finer the sand/silt particles the more prone to erosion the soil is likely to be. Thus, fine-grained siliceous parent material such as siltstones and rhyolites give rise to erodible soils, at least in surface units. Clays with dispersible behavior are frequently associated with the more siliceous parent materials, as they are more susceptible to sodium problems. According to Arbestain *et al*., (2007), parent material has an indirect effect on organic matter stability through the weathering rate and base cation release, which affects soil fertility and reactivity and through effects on soil drainage and root architecture, all of which in turn, affect above ground and below ground biological activity. Thus, the soil lithology has many, probably concomitant effects on the different organic matter stabilization mechanisms. According to FAO (2005), parent material influences organic matter accumulation not only through its effect on soil texture, soils developed from inherently rich material, such as basalt, are more fertile than soils formed from granitic material which contains less mineral nutrients. Moreover, the former experience more organic matter accumulation because of abundant vegetative growth.

2.7.1 Lithological composition of the three-parent materials studied

Coastal plain sand (Benin formation)

The Coastal plain sands which underlie the major part of the South -eastern Nigeria consists of unconsolidated yellow and white sand materials which are sometimes cross-bedded with clays, sand clays and sometimes pebbles (Orajaka 1975, FDALR 1985, Edet *et al.*, 1994). Soils on the Coastal plain sands are deep, highly weathered, strongly acid, coarse textured and generally of low total nitrogen (< 0.2 gkg^{-1}), organic matter (< 10 gkg^{-1}), effective cation exchange capacity, base saturation and inherent chemical fertility (Eshett 1991). Based on the description of FDALR, (1990), the Coastal plain sands consist of soft, very poorly sorted clayey sands, sandy clays and rare thin lignities. They further stated that Coastal plain sands are indistinguishable in the field from much of the Falsebedded sandstones and lower coal measures which show similar red and brown sandy earths. According to Onyeagocha (1980) the Coastal plain sand is predominantly sandy with clay intercalations. The sands are poorly cemented, fine to coarse grained, sub-angular to well rounded. Generally, the soil reaction is very strongly acid to strongly acid (pH 4.5 – 5.3), the exchangeable bases are low to very low for all cations with low to moderate cation exchange capacity and percentage base saturation (≤ 6 – 12 cmolkg^{-1}, ≤ 50 – 80 %). (Eshett, 1991). Okoye *et al.*, (1991) reported calcium content of ≤ 2 cmolkg^{-1}, magnesium content of ≤ 1.0cmolkg^{-1} and potassium content of ≤ 0.2cmolkg^{-1} in soils of the Coastal plain sands. Recently, similar range of values in the chemical composition of soils derived from the Coastal plain sands have been reported by Ogban and Ekerette (2001)., Obi and Udoh (2011)., Madueke *et al., (*2012). For instance, Obi and Udoh, (2011) reported effective cation exchange capacity of 5.4cmolkg^{-1}, 64.52% base saturation, 2.31cmolkg^{-1} of calcium and 1.05cmolkg^{-1} of magnesium in some soils developed on the Coastal plain sands of Nigeria.

Falsebedded sandstones (Ajali Formation)

The Ajali sandstone consists of friable – medium to fine – grained sands, averagely sorted, typically whitish in colour with characteristics cross – stratification thus the common reference as Falsebedded sandstone (Tijani *et al* 2010). The sand grain and fragment are sub-angular with a sparse cement made up of white clay (Okereke *et al* 2012). It is overlain by considerable thickness of red earth, which consists of red sands formed by the weathering and ferroginisation of the Shale occurring at intervals, increasing in number towards the base (Reyment 1965., Okereke *et al.*, 2012). They also reported the presence of marine fossils (mostly gastropods and oysters of probably maestrichitian age) in the Falsebedded sandstone. Tijani *et al* (2010) reported high proportion of quartz (> 90 %), little but significant quantity of potassium feldspar and the absence of more chemically unstable plagioclase and other labile components. According to FDALR (1990), the Falsebedded sandstones are shallow, well drained brown to strong brown gravelly and strongly cemented rock materials. Soil reaction ranges from very strongly acid to moderately acid (pH 4.8 – 5.9), with low exchangeable bases for all cations and low to moderate cation exchange capacity (3.75 – 8.51 cmolkg^{-1}).

Shale (Bende Ameki formation)

Shale is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. The ratio of clay to other minerals is variable (Blatt and Robert, 1996). They also stated that Shale is characterized by breaks along thin laminae or parallel layering or bedding less than one centimeter in thickness, called fissility. Shale typically exhibits varying degrees of fissility breaking into thin layers, often splintery and usually parallel to the otherwise indistinguishable bedding plane because of parallel orientation of clay mineral flakes (Blatt and Robert, 1996). Non-fissile rocks of similar composition but made of particles smaller than 0.06 mm are described as mudstones (1/3 to 2/3 silt particles) or clay-stone (less than 1/3 silt). Rocks with similar particle sizes but with less clay (greater than 2/3 silt) and therefore grittier are siltstones (Blatt and Robert, 1996). Shale is the most common sedimentary rock and are typically gray in colour. Addition of variable amounts of minor constituents alters the color of the rock. Black shale results from the presence of greater than one percent carbonaceous material and indicates a reducing environment (Herbert, 1996; Blatt and Robert, 1996). Red, brown and green colors are indicative of ferric oxide (hematite – reds), iron hydroxide (goethite – browns and limonite – yellow), or micaceous minerals (chlorite, biotite and illite – greens) (Blatt and Robert, 1996). Shales and mud rocks contain roughly 95 percent of the organic matter in all sedimentary rocks. However, this amounts to less than one percent by mass in an average shale. Black shales which form in anoxic conditions contain reduced free carbon along with ferrous iron (Fe^{2+}) and sulfur (S^{2-}). Pyrite and amorphous iron sulfide along with carbon produce the black coloration and purple (Herbert, 1996).

The Bende Ameki formation of the Eocene to Oligocene consists of medium-coarse grained white sandstone, bluish calcareous silt, with mottled shale and thin limestone (Reyment, 1965., Ibeneme *et al.*, 2014). Bende Ameki formation overlies the Imo shale group of Paleocene age, which is characterized by lateral and vertical variation in lithology (Akankpo and Igbokwe, 2012). According to Ibeneme *et al*., (2014), considerable lateral variation in lithology has been observed; the lower part of the formation consists of fine-coarse grained lenses of sandstones with abundant calcareous Shales and thin shelly limestone. However, the Bende Ameki and the Imo shale group include both marine and continental deposits with considerable clay fraction and sands that are usually coarse angular and poorly sorted (FDALR, 1990). Soils derived from the Bende Ameki Shale are generally deep, moderately to imperfectly drained, with dark gray sandy loam to sandy clay loam surfaces underlain by dark brown to brown, sometimes mottled sandy clay loam or clay sub-soils. Soil reaction is very strongly acid to moderately acid (pH 4.0-6.0) with low to moderate exchangeable cations and percentage base saturation with CEC ranging between 8.0 – 17.40 cmolkg^{-1} (FDARL, 1990). Law-Ogbomo and Nwachokor (2010) reported 5.92 – 7.92 cmolkg^{-1} of calcium, 0.8 -1.20 cmolkg^{-1} of magnesium and 0.20 – 0.26 cmolkg^{-1} of potassium in some soils derived from Shale in south-eastern Nigeria. Similarly, Onweremadu *et al*., (2011) reported calcium content of 6.49 cmolkg^{-1} in soils derived from Shale.

2.8 Land Use

Land use has been described as human modification of the natural environment or wilderness into built environment such as fields, settlements, pastures etc (Forley *et al*., 2005). According to FAO (2002), it is the arrangement, activities and inputs people undertake in a certain land cover type to produce, change or maintain it. Land use has different meaning to different professionals. Natural scientists defined it in terms of syndromes of human activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and bio-diversity, while social scientists and land managers define land use more broadly to include social and economic purposes within which land is managed or left unmanaged such as subsistence versus commercial agriculture, rented versus owned or private versus public land (FAO, 2002). In agricultural terms, land use refers mainly to the different practices that land is used for, such as arable farming, plantation agriculture, land under fallow etc.

Land use has been categorized into different major kinds, such as rain-fed agriculture, grassland, fish pond, forestry, grazing and tourism, and into primary or compound kind in which more than one kind of land use is practiced within an area (FAO, 2002). Generally, two broad categories of land use are widely reorganized namely, the productive and non productive land utilization types (Agboola, 1979). Agboola further stated that the productive land use involves the use of land for agricultural purposes such as forest, arable farming whereas the non productive land use involves the use of land for purposes other than agriculture (building and engineering). Of an estimated agricultural land area totaling 700,000 square kilometer in Nigeria, about 300,000; 27,000; 40,000 and 150,000 sq kilometers are currently used for annual crops, perennial crops, permanent pasture and forestry respectively (Anon, 2005).

Human activities on land vary and may have differential impact on it. According to Van Duivenbooden *et al.,* (1996), physical land use, land use purposes and land use circumstances constitute three major interacting aspects of land use in many agro ecosystems in West Africa. Onweremadu *et al.,* (2007c) defined biophysical land use as human interference in the functioning of any given agro-ecosystem. However, land use is related to vegetation and human construction on land surface, water bodies and bare soils (Mucher *et al*., 1993).

2.8.1 Common land use practices in Nigeria

Nigeria's land area of about 924,000 sq km in late 1980s supports 122 million people by the World Bank estimates (FDALR, 1999). Currently, Nigeria has a total land area of 910, 770 sq km of which 86% is classified as agricultural land, with about 41 % of the agricultural land being arable lands (World Bank, 2011). The rapidly growing population has resulted in a great pressure on the land. The area is devoted to a number of competing uses, which include agricultural, urban, industrial and commercial development. More often than not, land use practices in Nigeria do not take cognizance of the best land use option. The increasing population in Nigeria and its associated pressure on land use has led to the indiscriminate use of land without much consideration of the effects of such land use types and the long term consequences and options for multiple and renewable uses. Nuga (2001) reported that decisions on land use are being made indiscriminately based on economic and political considerations mainly, with just a little or no attention given to the biophysical status of the soil resource. Akamigbo (1999b) also reported that Nigeria's landmasses are facing intensive competitive use that very often led to their misuse and degradation. This in effect hinders meaningful national development. It is therefore pertinent that for the potentials of agricultural land to be maximized, there is the need to have an understanding of the different options (alternatives) the land can be put into. In other words, an effective land use planning is hinged on having qualitative and quantitative information on the land. Nair *et al*., (1999) stated that in order to optimize the utilization of land, it is necessary to devise plans to conserve and improve this vital natural resource.

In Nigeria, land use pattern is based on two main features of agricultural significance: the limited extent of cultivated land and the extensive area of residual land (Agboola, 1979). He further stated that the area under farm and tree crops constituted less than 10 % of the country's land resources. Even if forests were taken into consideration, land use for primary production as at 1960 agricultural sample census was less than 20 % of the total land (Table 2.3). Moreover, these national figures conceal considerably variations in the area of cultivated land from one part of the country to the other.

In 1990, estimates indicated that 82 million hectares out of Nigeria's total land area of about 91 million hectares were arable, however, only about 34 million hectares (or 42 percent of the cultivable area) were being cultivated at the time (CIA World Factbook 1991). Much of this land was farmed under bush fallow, a technique whereby an area much larger than that under cultivation is left idle for varying periods to allow natural regeneration of soil fertility. Another 18 million hectares were classified as permanent pasture, but much of this land had the potential to support crops. About 20 million hectares were covered by forests and woodlands. Most of this land also had agricultural potential. The country's remaining 19 million hectares were covered by buildings or roads, or were considered wasteland. The Federal Ministry of Environment of Nigeria 1993 estimate of irrigated land is 9,570 km^{-2} and arable land about 35 %; 15 % pasture; 10 % forest reserve; 10 % for settlements and the remaining 30 % considered uncultivable for one reason or the other (Folarin, 2011). Boomie (1998) corroborated the irrigated land at 9, 570 km^{-2} with arable land at 33 %; permanent crops 3 %; permanent pastures 44 %; forests and woodland 12 % and others 8 %. Cleaver and Shreiber (1994) put the surface area of Nigeria as 91.07 million hectares, 57 % of which is believed to be either under crops or pastures while the remaining 43 % is divided amongst forest, water bodies and other uses. However, Asadu *et al* (2004) stated that arable land constituted 31% while permanent crop land constituted 3 % of the total land area of the country (Table 2.5).The country has to rely on all available arable land to sustain its rapidly increasing population. Such a situation calls for proper land use planning and management to ensure that the sites are put to optimal use. To provide a sound basis for this, reliable information on various soils of the country is needed.

Table 2.3: Land use in Nigeria by Agboola (1979).

Land use type	Area in hectares	Total (%)
Residual	72825	78.9
Forest reserves	8405	9.1
Farm lands (Arable crops)	7603	8.3
Swamps	2699	2.9
Tree crops	502	0.5
Settlements	408	0.4

Table 2.4: Land mass distribution by use types in Nigeria (Total area: 923,768 sq km)

Land use types	**Total**
Land surface (sq km)	910,768
Water surface (sq km)	13,000
Arable Land (%)	31.29
	42 under cultivation
Permanent crop land (%)	2.96
Others (%)	65.75

Source: Metz, (1991), Asadu *et al*., (2004)

2.8.1.1. Continuous cultivation

This involves putting a particular piece of land under cultivation for unlimiting number of years. It is a common practice in areas where land is scarce. The decline of crop yield under continuous cultivation has been attributed to factors of soil nutrient mining, acidification, soil compaction and loss of soil organic matter (Juo *et al*., 1995). Agricultural soils, which cover around 37% of Earth's land surface, contain large amounts of carbon and other essential nutrients. But, in general, agricultural activity, and especially cultivation, causes a loss of soil carbon, and as a result, cultivated soils tend to have lower soil carbon contents than fallow soils, such as those of native grassland and forest (Schlesinger, 1999; Schlesinger and Lichter, 2001).

The removal of vegetation during cultivation can have a marked effect on the crusting potential of soils by exposing the soil to raindrops and altering soil properties such that the soil becomes more prone to crusting (Meyer *et al* 1996). **S**uch changes in soil properties expose the soil to erosion, a major causative agent for soil degradation. However, deficiencies of potassium (K) in root crops, sulphur (S) and zinc (Zn) in maize and Boron in groundnuts have been reported in continuously cultivated fields which have few or no input of crop residues or animal manure (Friessen, 1991). Aluminum toxicity and related calcium (Ca), magnesium (Mg), and phosphorus (P) deficiency encountered in most cultivated land due to the use of chemical fertilizers also limit the yield of cereals and legumes in acid soils of south-eastern Nigeria (Wilding and Hossner, 1989). The increased use of farm machines on agricultural lands has been reported by many researchers to have adverse effects on soil properties (Ohu and Folorunso, 1989). The adverse effects are reported to have been due to soil compaction created by farm machinery. The soil physical properties affected by compaction include; infiltration rate, bulk density and penetration resistance which in turn affect crop growth and development. The extents to which these properties may be critical for crops depend upon the soil type, climate, plant species and the stage of development of the crop. Bennie and Botha, (1986) reported that compaction from farm machine results in low infiltration rate, high bulk density, restricted root growth and low yield of crops.

Throughout south-eastern Nigeria, the slash and burn method has been widely used by small scale farmers as a means of land preparation and soil fertility maintenance. Slash and burn agriculture involves manual clearing, burning and cropping in a relatively small area of land for one or two years followed by a long period of natural fallow. This land is usually allowed to return to forest in other to restore fertility (Mokwunye and Hammond, 1992). Where the period of fallow has been shortened to less than two years, crop yield generally decreased rapidly creating a constant pressure to clear new lands (Ayodele, 1986). Burning encourages the loss of nitrogen, carbon and sulphur associated with organic matter to the atmosphere. Also large scale clearing accelerates soil erosion, surface sealing and crusting (Kooistra *et al*., 1990; Vander Water and Valentine, 1992). Continuous cropping of the alfisols, ultisols and oxisols in southern Nigeria has resulted in rapid decline in soil organic matter in surface of the soil during the first few years following land clearing (Brams, 1971).

Continuous cultivation of land causes a significant decline in soil pH organic matter and exchangeable calcium and magnesium levels. This is more pronounced when acidifying fertilizers are used (Juo and Kang, 1989). Degraded soils of the tropics are subjected to rapid mineralization of soil organic carbon and subsequently loss of soil organic carbon and CO_2 emission to the atmosphere especially in cultivation practices such as tillage and continuous cropping (Six *et al*., 2004). Land use practices that involve soil disturbances and removal of vegetation have been reported to cause losses of soil organic carbon to the atmosphere (Grant *et al*., 2001; Six *et al*., 2004). The amount of organic carbon in soil represent a balance between primary productivity, as influenced by environmental condition and biologically-mediated decomposition processes (Bulluck *et al*., 2002, Schroth *et al*., 2002). According to Terra *et al*., 2004), soil organic carbon is considered as an important soil quality indicator due to its significant effects on other soil properties such as soil aggregate stability, cation exchange capacity and bulk density.

2.8.1.2. Fallow land

Fallowing is one of the agronomic practices adopted to sustain the fertility of the soil. Farmlands may be abandoned to grow bush, hence are referred to as “bush fallow” or may be planted with nitrogen fixing plants which is referred to as planted/improved fallow (Styger and Erick, 2006). However, two major fallow systems are generally distinguished namely; fallows composed of natural vegetation and fallows that consist of deliberately planted species. Fallow management and improvement are as old as agriculture itself. Fallows are currently still intrinsic part of many tropical farming systems. The development of agricultural systems and the spatial dynamics of land use are strongly correlated with the evolution of fallows’ patterns. Indeed, some classifications of farming systems have been based on fallow characteristics (Boserup, 1965; Ruthenberg,1980).

While fallow is commonly referred to as resting period for agricultural land between two cropping cycles during which soil fertility is restored, it has more roles than just fertility restoration. Fallows functions include control of weed, interruption of pest and disease cycles, providing of cash income in times of immediate need and helping to balance food supply (Styger *et al.,* 1999), producing of wood, fibers and medicinal plants for household and serving as pasture for livestock (Styger and Eric, 2006). The oldest form of fallow management was shifting cultivation systems where very long fallow periods alternated with short cropping periods. A multitude of fallow systems have developed across the tropics over many centuries, diverging from this primordial model as farmers have developed diverse strategies for intensified fallow use. As populations grew and pressure on land area increased, fallow periods were reduced, and traditional fallow management was often not sufficient to restore soil fertility, leading over time to soil and vegetation degradation and noticeable declines in crop yield (Styger and Eric, 2006). The agronomic performance of agro-ecosystems can be enhanced by managing more efficiently the biological cycles and interactions among components that determine crop productivity. Improved fallow management as entry point has the potential to capture nutrients within the system and make them plant available, to reduce weed pressure, restore soil organic matter, litter layers and biological activity in the surface soil, and to rehabilitate soil macro and micro organisms that were reduced during the cultivation (Styger and Eric, 2006).

According to Power, (2007), improved fallow system involves the establishment of legumes and other improved plant species for soil fertility regeneration, soil erosion control and fodder production. The ability of legumes to fix atmospheric nitrogen and thereby add external nitrogen to the crop-soil ecosystems is a distinct benefit of legume culture. When fertilizer nitrogen is expensive or unavailable, crop production systems depend on the nitrogen fixed by legumes to maintain the nitrogen cycle at a sustained productive level (Power, 2007). He stated that the quantity of nitrogen biologically fixed each year by legumes varies greatly from zero to several hundred kilogram of nitrogen per hectare (kg N/ha). Improved fallow involving legumes enhances soil organic carbon content and mineralizable nitrogen, this provides not only better control of nitrogen availability, but also improved soil structure, less energy for cultivation and less erosion (Hoyt and Hargrove, 1986). Reduction in erosion rate over a period of decades can have a major influence on the properties and productivity of some soils (Mielke and Schepers, 1986).

The sustainable intensification of fallow and cropping systems provides continuous soil cover, maintains soil organic carbon and nitrogen, preserves nutrients within the systems and keeps nutrient cycling as efficient as possible, building on species diversity in fallows and in crops with each contributing according to its specific comparative advantages to overall increase of the systems productivity. Fallow enhances soil structure and improves air-water relations in the soil (Power, 2007). Soil organic matter increases the cation exchange capacity of the surface soil which is especially important in kaolinitic soils (FAO, 2005). Of special importance is its increasing soil organic carbon which can reduce soil degradation to the barest minimal. According to Agboola (1994), soil organic carbon accounts for 80% of cation exchange capacity (CEC), and available phosphorus, potassium and magnesium. In fallow land, fine surface roots of the fallow vegetation mould the soil into soft and porous granules or crumbs, worms deposit their casts on the soil surface, and drainage channels are created. Such a soil surface permits rapid infiltration of water and resists erosion unless completely unprotected. Biomass production, litter fall, and soil organic carbon influence microclimates and the substrates for soil fauna. Litter fall under fallows has been shown to increase micro arthropod and earthworm population in southwestern Nigeria (Salako and Tian, 2001). Fallow land within an agro-forestry systems in Amazonia has been seen to exert a favorable effect on the soil fauna, presumably by keeping the soil moist and shaded and by providing litter as a substrate (Barros *et al.,* 2003). In a comparison of a 15-year fallow and a 3-year potato field in the high tropical Andes, labile C and N soil pools under fallow increased significantly; microbial biomass nearly doubled; the microbial community was much more diverse; and the rate of plant material decomposition was much faster under fallow (Sarmiento and Bottner, 2002)

Generally, the central problem of tropical agriculture has been the inability of the land to sustain annual food crops for more than few years. All measures to increase food supply such as improved crop varieties, mechanization, integrated pest and disease management, better marketing systems cannot be successful unless the soil is in sustained condition to support crop growth and development (Ogukunle and Awotoye, 2011). It is obvious that continuous cropping for over a decade or half on these soils without stable means of fertility restoration will result in low yields. Fallow plays an important role in cropping systems. It accumulates soil water for subsequent crops because rain is often insufficient. According to Yemefack *et al*., (2002), the most important change in soil morphology during natural fallow re-growth was observed on top soil. This shallow surface horizons enriched in humus are dominant under the virgin forest and are known in most tropical regions as resulting from high mineralization rates of litter production (FAO, 1998). Fallowing and crop rotation can provide suppression of plant pest and diseases. Plant parasitic nematodes are among the major soil-borne pathogens that are suppressed effectively by bush fallow (Wilson and Cravenness, 1980). Forage legumes and other plants in the bush fallow particularly, prostrate types such as *Centrosema pubensence*, *Pueraria phaseoloides* and *Mucuna pruriens* compete with other weeds successfully when well established.

2.8.2 Effects of land use on soil quality and land degradation

2.8.2.1 Land and soil degradation

In all parts of Nigeria, there is noticeable evidence of land degradation. This varies from place to place in terms of the types, duration, severity and socio-economic impact (Aruleba, 2004; Senjobi, 2007). A survey in 1990 by United Nations suggested that a quarter of the worlds' total crop land is affected by degradation severely enough to restrict its productivity, 15.6% of this compromised agricultural land is strongly degraded land whose original biotic functions including nutrient cycling are largely destroyed (Senjobi and Ogunkunle, 2011). This has resulted in production loss of about 17% on degraded lands. Accelerated land degradation processes have been attributed not only to rapid human population growth, but also to concomitant intensification of land use. In the last 50 years alone, 20% of the world’s agricultural land has been irreversibly damaged, and if the process of destruction continues at this pace, agriculture could lose 15 to 30% of its productivity (FAO, 1984). During 1945 to 1990, human induced land degradation in Africa exceeded 494 million hectares, and only 22% of the total land area constitutes the producing biomass (Senjobi and Ogunkunle, 2011). According to Lal, (1990), annual estimate of land lost to land degradation via improper land use was expected to rise from 5 to 7 million hectares in 1981 to 10 million hectares in the year 2000. On the other hand, soil degradation is a decline in soil quality and productivity through misuse. The current and potential capacity of the soil to produce food, feed and fibre crops diminished as a result of one or more degradative processes which may include both physical, biological and chemical deterioration due to erosion, desertification, laterization, salt accumulation, excessive leaching, acidification and nutrient imbalance, water logging, surface and subsurface compaction, and pollution through fertilization, pesticide application, waste disposal, or even acid rain (Akamigbo, 2010b). He further stated that the most anthropogenic cause of soil degradation is inappropriate land use which impact negatively on the economic advancement of a nation.

2.8.2.2 Land use impacts on Soil physical, biochemical and morphological properties

Land use has significant influence on soil fertility and productivity which manifests as changes in soil properties such as nutrient content, pH, CEC and soil structure (Akamigbo and Asadu, 2001; Aluko and Fagbenro, 2000). For instance Aluko and Fagbenro, (2000) observed increase in organic matter and soil pH in soils under *Gmelina aborea* than those under *Pinus canaborea*, *Treculia africana*, agro-forestry and fallow. Also, Akamigbo and Asadu (2001) reported marked changes in morphological, physical and chemical properties which resulted to accelerated pedogenic processes and a decline in fertility of soil under traditional than forest land use. Land use changes, especially cultivation of deforested land may rapidly diminish soil quality leading to severe land degradation (Nardi *et al.,* 1996). Conversion of forest to annual crop cultivation and grazing land has been shown to influence changes in soil properties (Kimigo *et al*., 2008). Gal *et al*., (2006) showed that there is considerable decline of total N, soil organic carbon, soil total carbon, soil inorganic carbon, calcium carbonate ($CaCO_3$) and percentage base saturation when forest land is converted to agricultural use. The conversion of forest to crop land has been associated with reduction in organic components of the soil (Singh and Singh, 1996) and subsequent decline in productivity (Palm *et al*., 2001). Poor land use and management for agriculture often results in soil particles desegregation, thereby increasing soil bulk density (Michel *et al*., 2010). Globally, the major consequences of poor land use and management have been deforestation, urban sprawl, soil erosion, soil degradation, salinization and desertification (United Nation Land Degradation and Land Use, 2007). According to United Nation report on climate change in 2007, the land use change, together with use of fossil fuels, are the major anthropogenic sources of CO_2, a dominant green house gas.

Assessing land use-induced changes in soil properties is essential for addressing the issue of agro-ecosystem transformation, carbon sequestration and sustainable land productivity. In the tropics, carbon and nitrogen are sensitive to changes in land use. Michel *et al*., (2010) reported that a loss of up to 27% of carbon and nitrogen was recorded when natural forest soil was converted to agricultural land. Because soil carbon is important for the overall carbon reservoir of the biosphere and plays a preponderant role in the global biogeochemistry cycle of major nutrients, it has been used extensively by several authors to monitor land cover and land use-change patterns (San Jose and Montes; 2001, Koukita *et al*., 2002). Alvarez and Alvarez, (2000) further stated that though they are sensitive to land use changes, soil carbon and nitrogen, as well as microbial biomass, have been proposed as indicators for assessing the effect of land use management on soil.

2.9 Soil classification

According to Akamigbo (2010b), soil classification is the systematic arrangement of soils into groups or categories on the basis of their characteristics. Broad groupings are made on the basis of general characteristics and sub divisions on the basis of more detailed differences in specific properties. More so, soil classification deals with the systematic categorization of soils based on distinguishing characteristics as well as criteria that dictate choices in use (Eswaran *et al*., 2002). Soil classification is a dynamic subject, from the structure of the system itself to the definitions of classes, and finally in the application in the field. Soil classification can be approached from the perspective of soil as a material and as a resource (Buol, *et al*., 1997).

Generally, classification of soils of any given location helps in generating soil and soil-related data which are useful in predicting soils for their sustainable uses (Onweremadu *et al*., 2007c). Appropriate and proper use of soils depends upon the characteristics of such a soil, there is therefore need to characterize and classify them in a manner that will ease communication and transfer of knowledge about such soils to farmers and other land users (Nuga *et al*., 2008). On the basis of organic matter content, soils are classified as mineral (inorganic) or organic soils (FAO, 2005). Mineral soils form most of the worlds cultivated land and may contain from a trace to 30% organic matter (Soil Survey Staff, 2003). Organic soils are naturally rich in organic matter containing more than 30% organic matter principally for climatic reasons and are not vital cropping soils.

For soil resources, experience has shown that a natural system approach to classification that is,. grouping soils by their intrinsic property, behavior, or genesis, results in classes that can be interpreted for many diverse uses (Driessen *et al*., 2001). There are many soil classification systems in the world, but close attention will be given to World Reference Base of the FAO and USDA Soil Taxonomy (Table 2.5).

World Reference Base

World Reference Base (FAO *et al*., 1998) is the successor of the International Reference Base for soil classification (IRB), an initiative of FAO, supported by the United Nations Environment Programme (UNEP) and the International Society of Science (ISSS), dating back to 1980. The intention of the IRB project was to work towards the establishment of a framework through which existing soil classification systems could be correlated and through which ongoing soil classification work could be harmonized (Dudal, 1996). According to Nachtergaele *et al*., (2000), the WRB comprises two tiers of detail: the “Reference Base” , which is limited to the first (highest) level, having 30 reference soil groups; and the “WRB Classification System” suggesting combinations of adjectives to the Reference Soil Groups, which allows precise characterization and classification of individual soil profiles. The most important innovation in the World Reference Base is the building-block approach. The building blocks are the uniquely defined qualifiers as described above. There are 121 of these, which compares favourably with the 152 different soil units in the Revised Legend of the FAO Soil Map of the world.

The USDA Soil Taxonomy

The USDA Soil Taxonomy - an American system of soil classification that is based on measurable morphological properties was modified in 1951 with several new ideas such as a new nomenclature and the introduction of diagnostic horizons (Soil Survey Staff, 1975; Akamigbo, 2010). However, after a series of amendments, a final copy of the classification was published in 1975 by Soil Survey Staff, as “Soil Taxonomy: a basic system of soil classification for making and interpreting soil surveys (Soil Survey Staff, 1975). Following this comprehensive publication, publications were made in 1999 (Soil Survey Staff, 2003) and finally in 2010 (Soil Survey Staff, 2010). Generally, Soil taxonomy makes use of specific characteristics which are peculiar to certain soil forming processes, including soil temperature and moisture. The USDA Soil Taxonomy has 12 Orders, 68 Suborders, 317 Great groups and 2434 Subgroups with categories of Family and Series which do not have specific numbers (Akamigbo, 2010).

Table 2.5: Comparison between WRB and Soil Taxonomy for soils in the tropics

WRB	Soil Taxonomy
Ferralsols	Oxisols pp.
Nitisols	Oxisols – kandiudox pp
Plinthosols	Oxisols – plinthaquox pp, ultisols – plinthudults pp
Lixisols	Alfisols – ustalfs pp., udalfs pp
Acrisols	Ultisols – udults pp., ustults pp
Alisols	Ultisols – udults pp
Gleysols	Inceptisols – Aquepts pp, Entisols – Aquents pp
Planosols	Alfisols – Abrupt Albaqualf pp
Solonchaks	Aridisols – Salorthids pp
Solonetz	Aridisols – Natrargids pp
Gypsisols	Aridisols –Gypsids pp
Durisols	Aridisols – Durids pp
Calcisols	Aridisols – Calcids pp
Arenosols	Aridisols –Psamments pp
Regosols	Entisols pp
Near - perfect match	
Histosols	Histosols
Vertisols	Vertisols
Andosols	Andisols

Source : Nachtergaele *et al*., (2000).

2.9.1 Classification of Nigerian Soils

Soil survey and classification started in Nigeria about six decades ago. The first work aimed at the taxonomic classification of Nigerian soils was carried out by Vine (1954) who divided the soils into three broad zones, which were further divided into 16 soil groups based on differences in mechanical compositions and organic matter contents (Ojanuga and Awojuola, 1971). Vine further defined “Soil fasees” roughly equivalent to families at the level of his classification system. He divided the soils of Nigeria into 27 “Fasees” which he grouped together into three separate zones of latosol, based on the degree of leaching and horizon content of the profile (Ojo – Afere and Oladimeji, 1977). Ohaeri, (1961) recognized a wide level of Coastal plain in these soil groups, less well drained part, the delta; the Coastal plain is connected with the sea by a large number of creeks. Jungerius and Levelt, (1964) studied the clay mineralogy of soil over the sedimentary rocks in Eastern Nigeria and observed that the soils in this area derived most of the clay mineral from the underlying rocks, and Kaolinite is dominant in all the soils.

More so, at a scale of 1: 1,000,000, soils of Eastern Nigeria were grouped into two board groups: “Acid sands (Doyne *et al.*, 1938) and ferrallitic soils (Jungerius, 1964). Jungerius, in his work observed that the Coastal plain sands are the youngest formation, which covers the wide plain extending from Owerri Southward to the coastal areas. Although soil survey started with Vines work in 1954, more comprehensive work with the production of soil map was done by Smith and Montgomery (1962); Federal Department of Agricultural Land Resources (FDALR, 1985; FDALR, 1990). The Federal Department of Agricultural Land Resources exercise resulted in the grouping of Nigerian soils into 5 soil groups showing different characteristics associated features of the soils based on the three broad ecological zones, twenty four broad geomorphic units as well as parent materials. Examples of such soil groups are mapping unit 431 derived from Coastal plains sands (FDALR, 1985) and mapping unit 12a derived from a mixture of Coastal plain sand and Sandstone (FDALR, 1990). These mapping units (431 and 12a) are among the soils classified by Lekwa and Whiteside, (1986) and Ohiri *et al.,* (1989) in the defunct Imo State as Typic Paleustults, Typic Paleudults, Grossarenic Tropaquod, Arenic Paleustults and Typic Paleaquults.

According to Fagbami and Ogunkunle, (2000) the FDALR soil map of Nigeria has credibility problems and too small a scale to give satisfactory direction on project site selection, soil management and land use planning. Esu, (2004) however contended that as far as food security and environmental sustainability determinations are concerned, these maps are of little or no value. This was probably why it was only supposed to be the Phase One of the Soil Survey and Land Evaluation Programme (FGN, 1997). The Phase Two of the programme focusing on semi-detailed and detailed surveys, providing more reliable characterization, classification, and detailed information necessary for the optimum conservation and utilization of land resources was however, not executed.

Based on this, other soil classifications were done in Nigeria using soil taxonomy (USDA) and FAO-UNESCO systems of soil classification. Okoye *et al*, (1991) grouped the 58 soil mapping units generated from the classification of the Federal Department of Agricultural Land Resources into four groups: each group is made up of mapping units in a given number of contiguous states that make up the group. In the Eastern states consisting of Akwa Ibom, Anambra, Cross River, Imo, Bendel (now Delta state) and Rivers State for instance, 26 soil mapping units are derived.: Soil mapping unit 6a; occupying about 1,523.52 sq km of the total land area of Nigeria, derived from the Coastal plain sands is composed of very deep well drained Typic Paleudults, Orthoxic Tropudults, Arenic Paleudults and Oxic Dystropepts as well as other minor soils (Okoye *et al* (1991), FDALR (1990). They further reported that the Typic Paleudults can be found around Mgbidi, Orji, Owerri-Ebeiri, Ikeduru, Ohaji, Asa and Akwete all in Imo state. It can also be encountered around Uyo, Abak, Etinan, Ekparakwa Nung in Akwa Ibom and Cross River states. The Orthoxic Tropudults may be encountered along Asaba – Benin road while the Arenic Paleudults occur around Akwete in Imo State and Ikot – Abasi in Akwa Ibom state.

Another mapping unit consisting of soils of South Eastern Nigeria is mapping unit 9a derived from sandstone and Shale principally of the Falsebedded sandstones, Imo shale and Bende Ameki shale (FDALR 1990). This soil mapping unit occurs in Imo, Anambra, Bendel and Akwa Ibom States and composed of deep well drained Typic Paleudults, Lithic Hapludalfs, Typic Hapludults, Oxic Dystropepts (Table 2.6) and other soils of minor extent. The lithic Hapludalfs occur around Okigwe area of Imo state (Tijani *et al.*, 2010) and Auchi area of Bendel state. Mapping unit 12a underlain by the Coastal plain sands and Sandstone occurs in Imo, Cross River, Akwa Ibom and Bendel States. In Imo state, it occurs on the Eastern parts of the state extending through Abiriba, Ohafia, Arochukwu, Umuahia and at the south eastern parts from where the unit stretches into the northern parts of Akwa Ibom state. Chukwu, (2013) in his study identified three soil series from this mapping unit (431 – FDALR, 1985, 12a – FDALR 1990) namely Alagba soil series (Aquertic chromic Hapludalf), Orlu series (Typic Paleudults, Haplic Paleudults) and Ahiara series (Aremic kandiudult, Arenic and Grossarenic Paleudults).

In addition to this, some soils of South-eastern Nigeria were recently classified as Typic Paleudults (USDA) – Dystric Nitosols (FAO-UNESCO) for Bende soils derived from Bende Ameki Shale group; Arenic Hapludults (USDA) – Dystric Nitosol (FAO-UNESCO) for Owerri soils derived from Coastal plain sand and Typic plinthaquox (USDA) – Vertic Plinthosols (FAO-UNESCO) for Okigwe soils (Onweremadu 2007a). Ojanuga *et al*, (1981) classified selected acid sands of South-eastern Nigeria while Eshett, (1987) classified the basaltic soils of Ikom areas, South-eastern Nigeria as Typic Paleustults and Typic Haplustults

Table 2.6: Taxonomic classifications of some soils (Mapping units) of south eastern Nigeria

Mapping Units No	USDA Classification	FAO Classification
6a	Typic paleudult	Dystric Nitosol
	Orthoxic Tropudult	Dystric Acrisol
	Arenic Paleudult	Dystric Nitosol
9a	Lithic Hapludalf	Orthic Luvisol
	Typic Paleudalf	Orthic Luvisol
	Typic Hapludult	Orthic Acrisol
12a	Typic Paleudult	Dytric Nitosol
	Typic Tropudult	Ferric Acrisol
	Typic Tropaquept	Eutric Gelysol
19a	Typic Paleustult	Chromic Luvisol
	Oxic Haplustult	Ferric Acrisol
	Oxic Paleustult	Dystric Nitosol

Source: FDALR (1990), Okoye *et al.,* (1991)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted in Imo (Umulolo, Okigwe and Umuagwo, Ohaji) and Abia (Itumbuzo, Bende) States in the Central Southeastern Nigeria. Both states lie between latitudes 4^{o} 40^{1} and 8^{o} 50^{1} North; and longitudes $6^{o}40^{1}$ and $8^{o}15^{1}$ East (Fig.3.1). Soils of the central south-eastern Nigeria are derived from Coastal Plain Sand (Benin formation), Falsebedded Sandstones (Ajali formation), Upper Coal Measure (Nsukka formation), Lower Coal Measure (Mamu formation) and Shale (Bende-Ameki formation). In addition to these are alluvium formed by fluvial and lacustrine activities (Orajaka, 1975, Atlas of Imo State Geology, 1984)

Central southeastern Nigeria belongs to the humid tropics with total mean annual rainfall ranging from 1500-3000 mm and total mean annual temperature ranging from 21-35^{0}C (National Root Crop Research Institute Umudike Meterological Unit, 2012). The relative humidity of the area is high (above 80%) throughout the year especially during the rainy season. Geomorphologically, It is dominated with lowland areas except for the high rising terrain of the North-eastern section of the area. It lies within the rainforest vegetation which originally was characterized by multiple plant species arranged in tiers with the southern part being denser than the northern part. The vegetation of the area consists of common tree species such as Gmelina (*Gmelina aborea*), Oil palm (*Elaeis guineensis*), Oil been tree (*Pentaclethra macrophylla*), and Bush mango (*Irvingia gabonensis*); grasses and wild legumes such as Goat-weed (*Sida acuta*), wild groundnut (*Calapogonium mucunoides*,) butterfly pea (*Centrosema pubescens*), Elephant grass (*Pennisetum purpurem*), Giant star grass (*Cynodon plectostachyus*), Siam weed (*Chromolena odorata*), and arable crops like cassava (*Manihot esculenta*), Banana (*Musa sapientum*) and Paw-paw (*Carica papaya*);. The Imo river. Ogochie river, Oramiriukwa river, Mamu river and Oguta lake, Otamiri, Orashi, Njaba rivers among other water bodies govern the hydrology of the area. The socio-economic activities of the area include farming, fishing, hunting, sand and stone mining; and quarrying plus a variety of cottage industries. In agriculture, soil fertility regeneration is by bush fallowing, while slash and burn is the major land clearing technique.

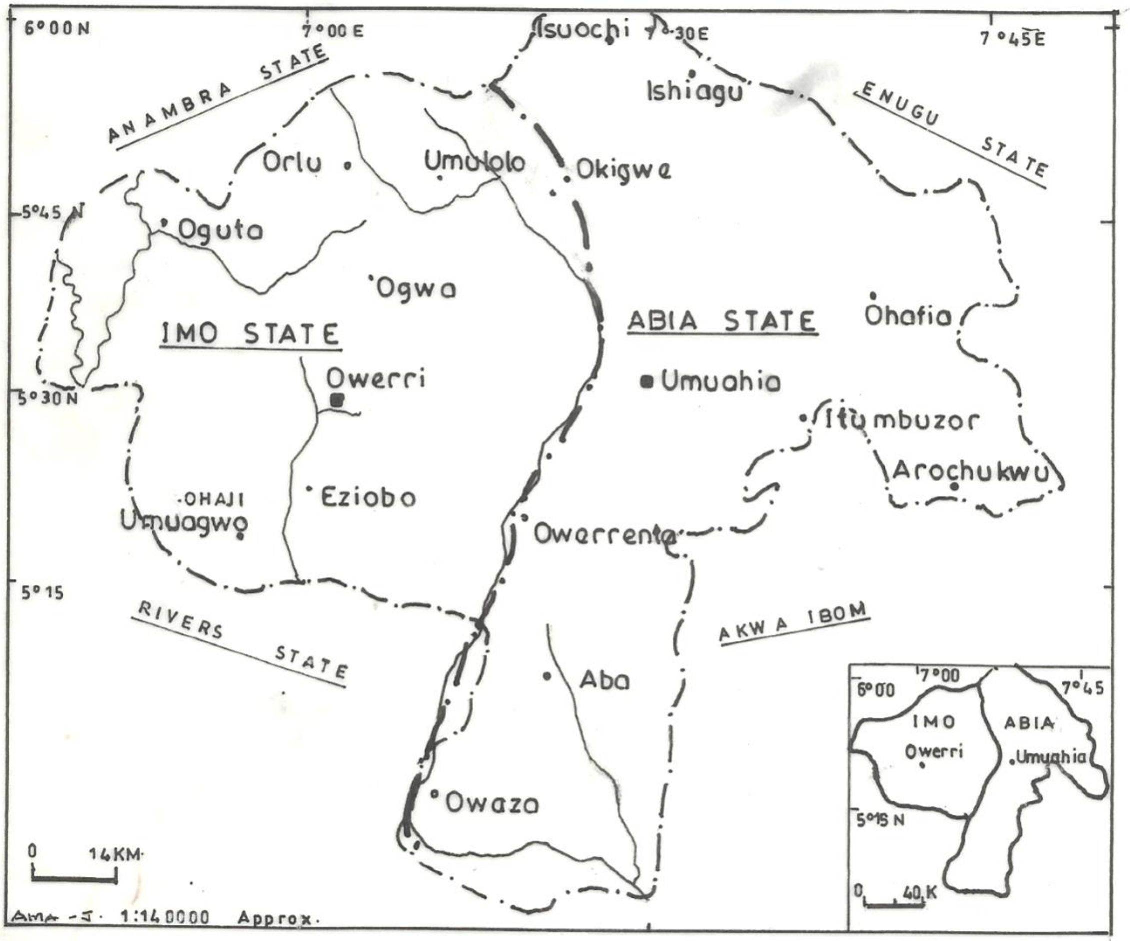


Fig 3.1: Location map of the study areas (Imo and Abia States)

Source: Geology Department, FUTO (2010).

3.1.1 The Physical Environment of various Study Areas

Umulolo Okigwe

Umulolo Okigwe lies between latitudes 5^{o} 52^{1} 20.5^{11} N and longitudes 7^{o} 17^{1} 51.7^{11} E (Fig.3.2). Geomorphologically, Umulolo Okigwe is dominated by lowlands and fairly uniform landform of low relief which exhibits a gently or slightly rolling toposequence (Ofomata, 1975). The area is underlain majorly by Falsebedded Sandstones (Maastrichtian Ajali Sandstone) (Fig. 3.3) (Tijani *et al*., 2008) and proximal to the Upper coal measures (Nsukka formation) of the Danian geologic era. The soils consist of friable – medium to fine – grained sands, averagely sorted, typically whitish in colour with characteristics cross – stratification thus the common reference as Falsebedded sandstone (Tijani *et al* 2010). The sand grain and fragment are sub-angular with a sparse cement made up of white clay (Okereke *et al* 2012). It receives an average of 2134 mm of rainfall distributed to about 139 days of the year. It has double maxima, with an August break occurring in July or August (NIMET, 2008). The daily temperature ranges from a minimum of 21^{o}C to a maximum of 29^{o}C. The relative humidity reaches a minimum of 60 % in January (at the peak of the dry season) and rises to 80 - 90 % in July (at the peak of the rains) (NIMET, 2008). The original vegetation of the study area was the tropical rainforest (Igbozuruike, 1975; FDALR, 1985). The rain forest has however been destroyed largely through human activities and supplanted with what is today referred to as the oil palm bush.

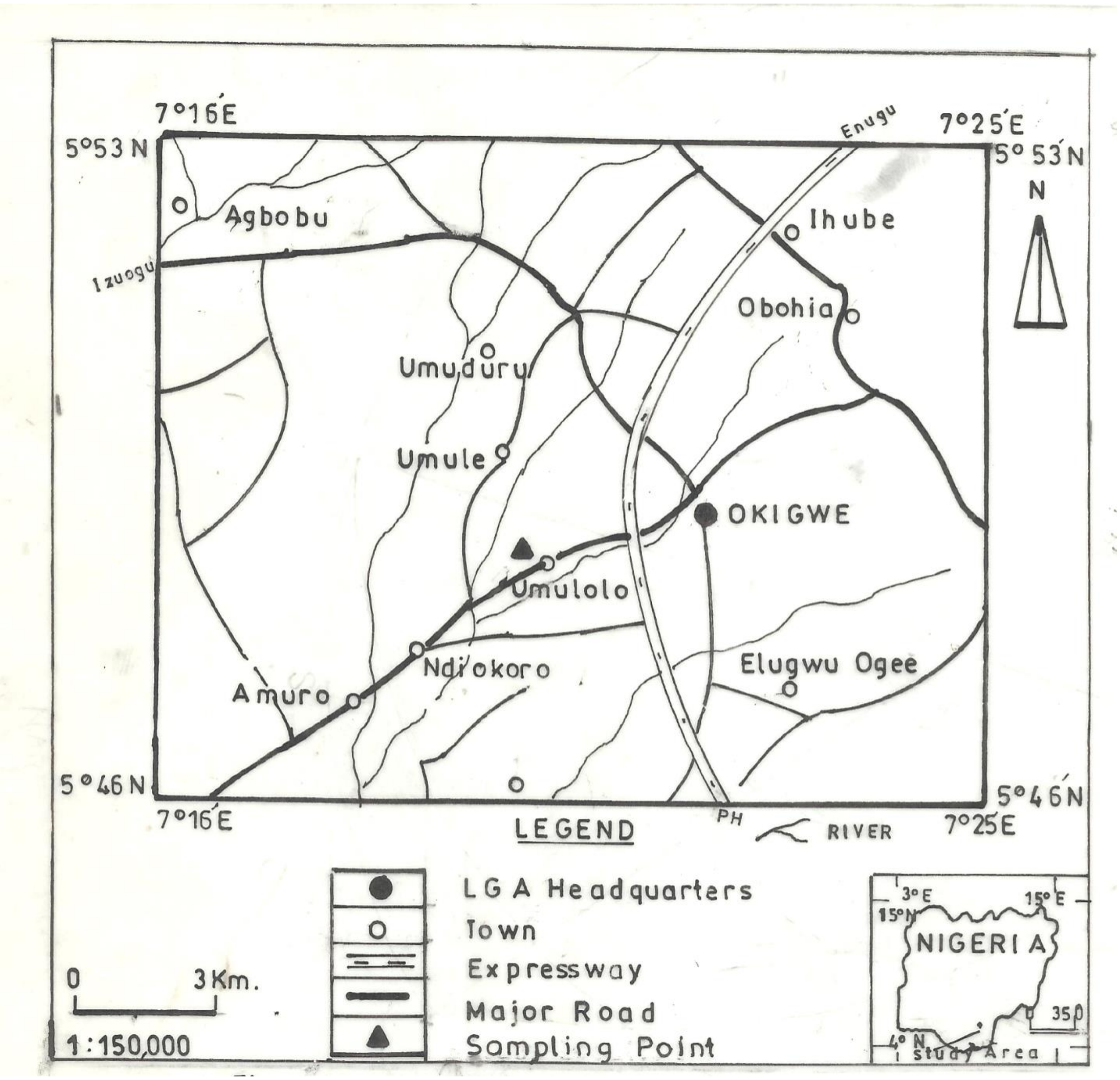


Fig 3.2: Location map of Umulolo, Okigwe

Source: Geology Department, FUTO (2010).

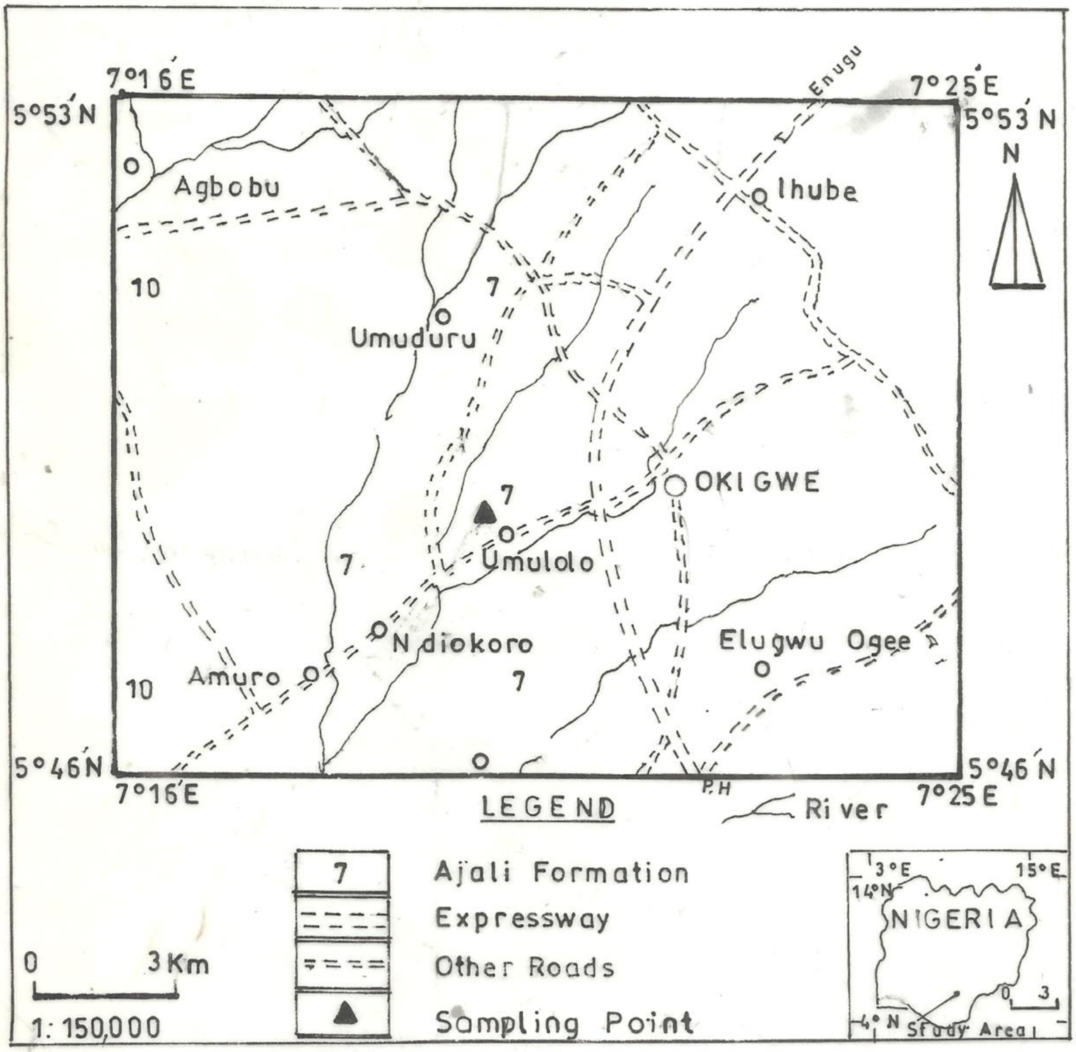


Fig. 3.3**.** Geology map of Umulolo, Okigwe
source: Atlas of Imo State Geology, (1984)

Umuagwo, Ohaji-Egbema

Ohaji lies between latitudes 5^{o} 19^{1} 29.4^{11} N, and longitudes 6^{o} 58^{1} 32.6^{11} E (Fig 3.4). The geology of the region is characterized by Coastal Plain Sands, Alluvium and Sombreiro-Warri Deltaic plains (Atlas of Imo State Geology, 1984). Coastal plain sands which underlie a major part of Ohaji (including Umuagwo) consist of unconsolidated sand materials which are sometimes cross-bedded with clays, sandy clays and sometimes, pebbles (Orajaka, 1975; FDALR, 1985). Soils on Coastal plain sands are deep, strongly acidic, coarse-textured (loamy sand to sandy loam), easily eroded and generally of low inherent fertility (Eshett, 1991; Osuji *et al.*, 2002). Physiographically, the landscape comprises of low-lying plain area with almost no portion of the town exceeding 175 m above sea level. It belongs to the humid tropics with total mean annual rainfall ranging from 1500-2550 mm and total mean annual temperature ranging from 21-30^{o}C (NIMET, 2008). The relative humidity of the area is relatively high throughout the year especially during the rainy season (above 80%).

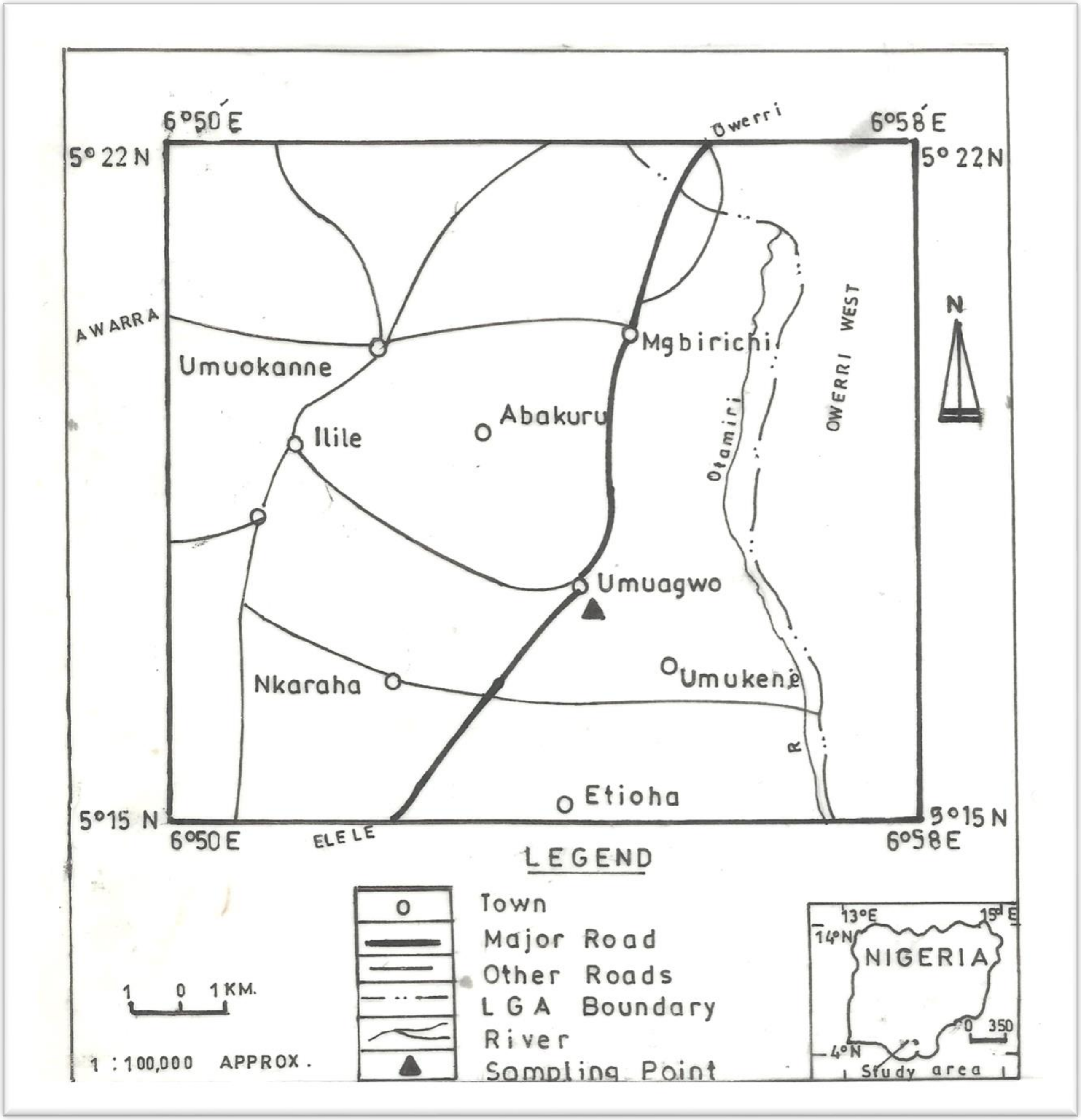


Fig 3.4: Location map of Umuagwo, Ohaji-Egbema

Source: Geology Department, FUTO (2010).

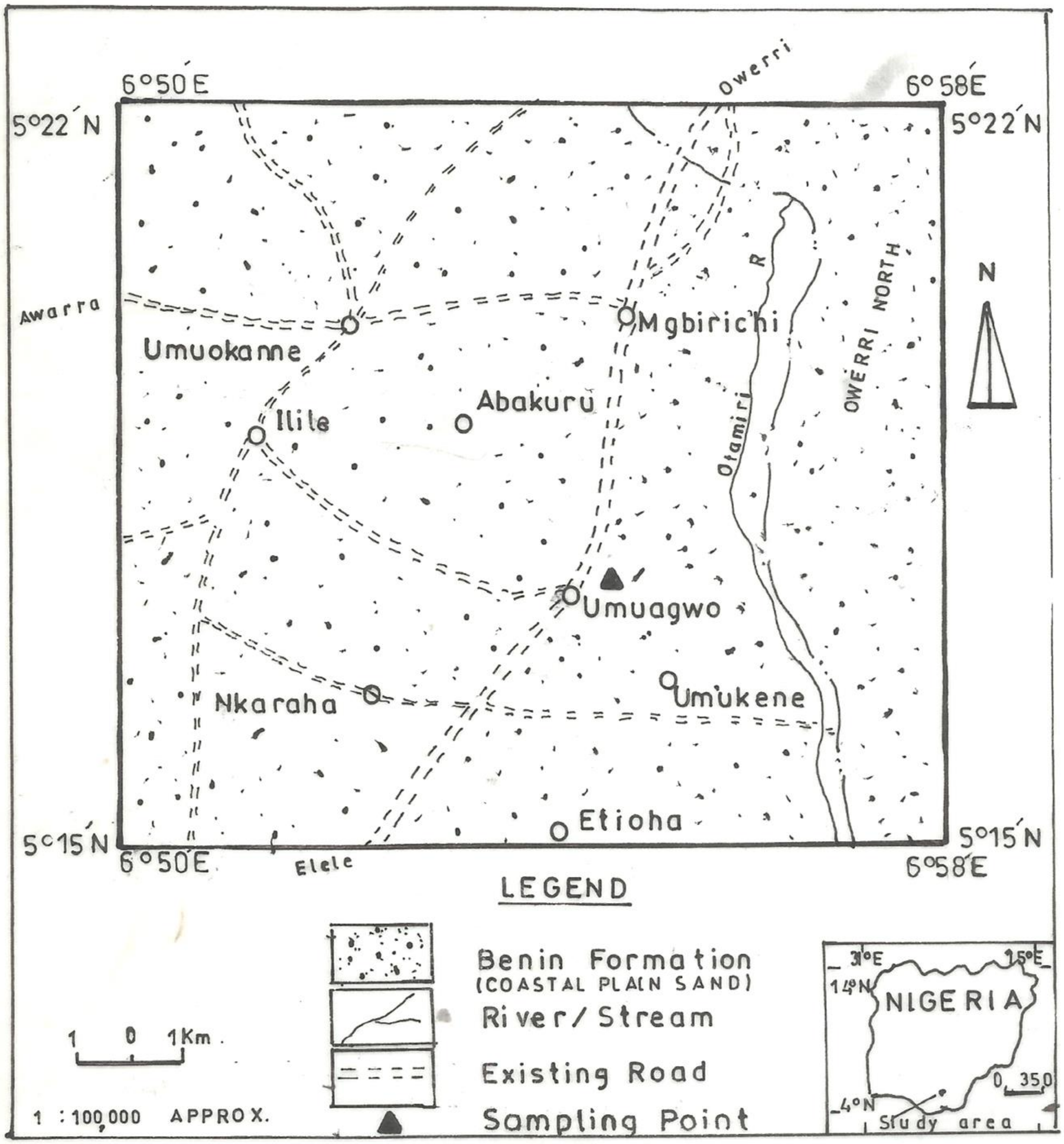


Fig. 3.5**.** Geology map of Umuagwo, Ohaji-Egbema
Source: Atlas of Imo State Geology, (1984)

Itumbuzor -Bende

Itumbuzor is located in Abia State, Southeastern Nigeria, between latitudes 5^{o} 50^{1} 37.5^{11} N, and longitudes 7^{o} 68^{1} 04.2^{11} E in the rainforest agro-ecological zone (Fig.3.6). Geomorphologically, Itumbuzor has hilly to undulating land form. Soils are formed from Bende – Ameki Shale Group (Fig.3.7). The Bende-Ameki Shale Group underlies a relatively narrow strip of land north of Umuahia and the entire old Bende extending westwards are dominated by plains under 200m above sea level (Chikezie *et al.*, 2008). Soils derived from this geologic material are generally deep, moderately to imperfectly drained with dark gray sandy loam to sandy clay loam surfaces underlain by dark brown to brown clay sub-soils with moderately to coarse structure. The climate is humid tropical with distinct wet season (April to October) and dry season (November to March). Annual rainfall in the area ranges from 1750 mm - 2500 mm with peaks in July and September. Average temperature ranges from 22 – 30^{0}C. Agriculture is a major socio-economic activity of the area (National Root Crop Research Institute Umudike Meterological Unit, 2012). Land clearing is by slash-and-burn technique while soil fertility regeneration is by bush fallowing whose length has decreased due to anthropogenic activities such as bush burning and land clearing.

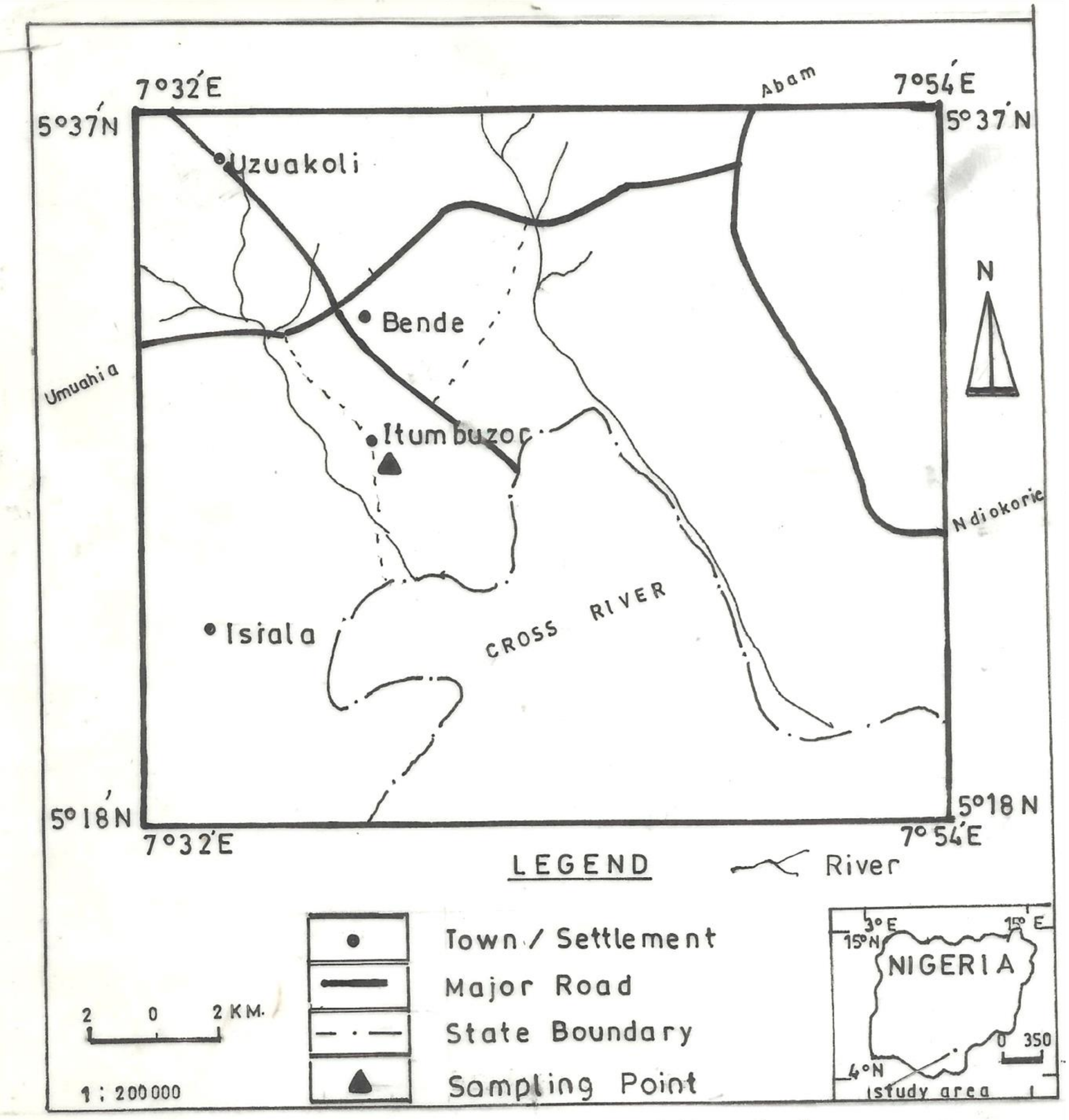


Fig 3.6: Location map of Itumbuzor, Bende

Source: Geology Department, FUTO (2010).

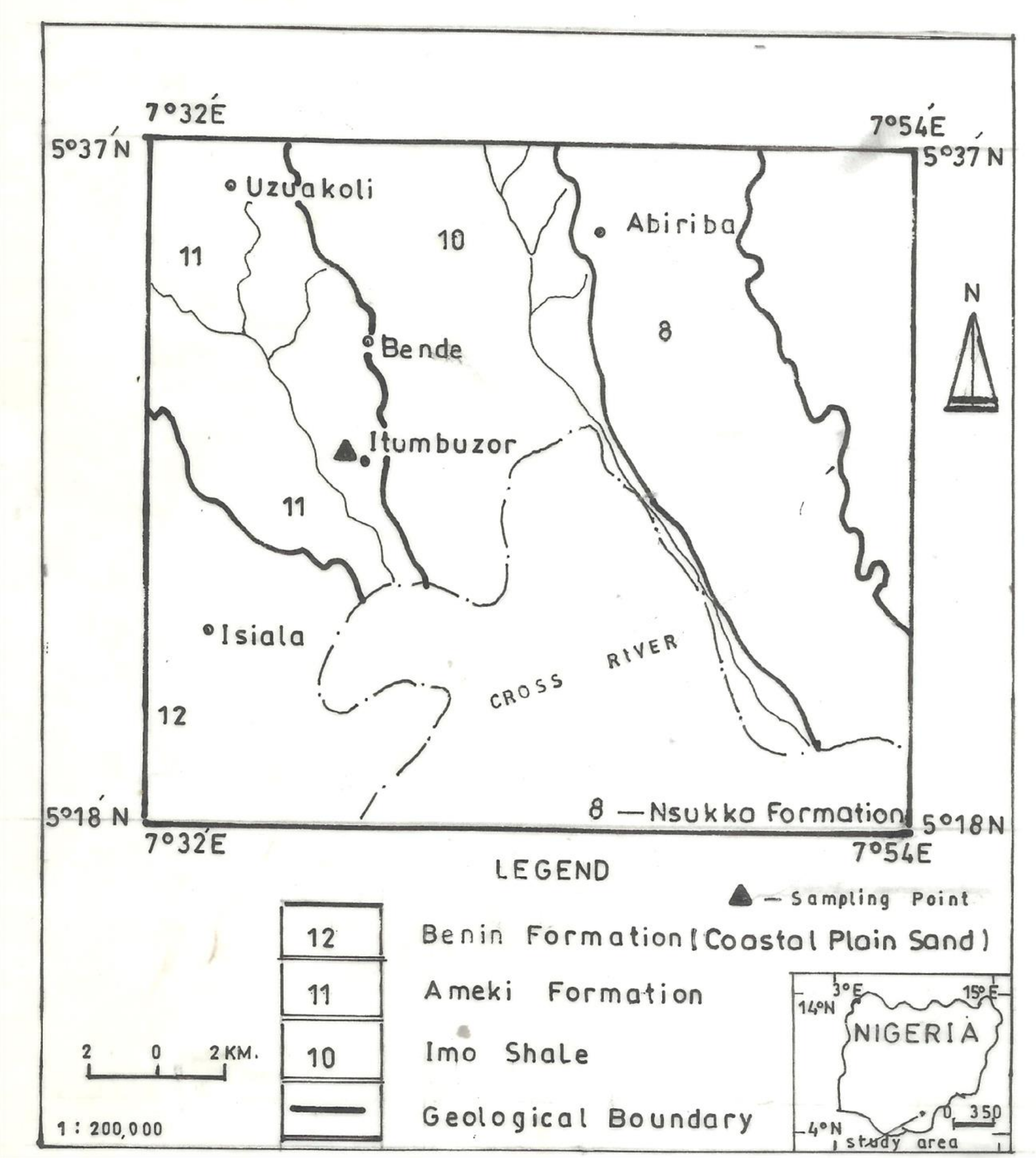


Fig. 3.7. Geology map of Itumbuzor
Source: Atlas of Imo State Geology, (1984)

3.2 Field study

A reconnaissance visit was conducted on the study sites with the aid of location and geology maps of the study areas in early 2010 to identify the different parent materials and land use types. Geology maps (Figs. 3.3, 3.5 and 3.7) were used to guide the location of the sampling areas based on their lithologies. Random sampling technique was used to locate the parent materials and the different land use types. Three parent materials namely Falsebedded Sandstones (Ajali formation) located at Umulolo in Okigwe, Shale (Bende-Ameki group) at Itumbuzo in Bende, and Coastal Plain Sands (Benin formation) located at Umuagwo in Owerri were studied, three land use types (secondary forest, cultivated and fallow land) occurring within a distance of 100 – 1000 m to one another were selected in each of the three different geologic zones. Three profile pits were dug at unequal distances in each of the varying land use types. A total of 27 profile pits were dug and sampled. Profile description and sampling were done according to the guidelines of FAO, (2006). Delineation of horizon boundaries was accomplished before actual sample collection for laboratory analyses. Macro-morphological properties of the various horizons were determined in the field and samples were collected based on horizon differentiation from the soil profile pits. Undisturbed core samples were collected for bulk density determination. The profile pits were geo-referenced using Handheld Global Positioning System (GPS) Receiver – Garmin Ltd Kansas, USA. Soil colour was determined using Munsell soil colour chart (2009) while other morphological properties (consistence, root composition and structure) were determined by visual observation, hand feeling and measurement. Small portion of each soil sample was air dried, crushed and sieved using a 2-mm sieve in preparation for laboratory analysis. Wet samples were used for the determination of available nitrogen forms.

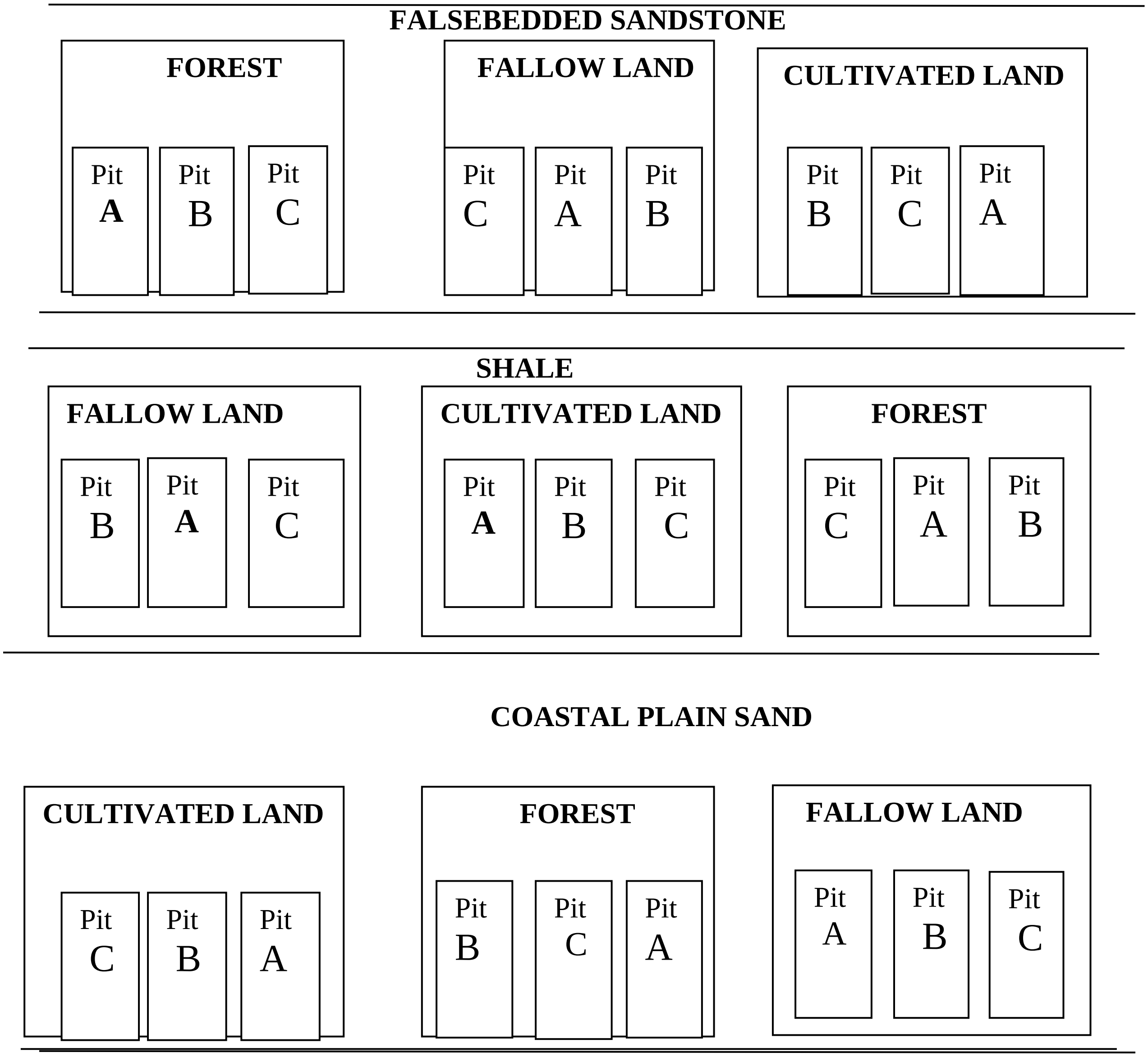


Fig. 3.7. Layout of soil profile pits in each of the study areas.

3.3 Experimental Design

The experiment was a factorial experiment (Fig.3.7) arranged in a randomized complete block design (RCBD) with the 3 (three) parent materials (Falsebedded Sandstones, Shale, and Coastal Plain Sand) being factor A, and the 3 (three) land use types (forest, cultivated and fallow land) serving as factor B, 3 (three) profile pits in each land use type serving as blocks, giving a total of 27 profile pits; 3 x 3 x 3 = 27 profile pits

3.4 Laboratory analysis

The physical and chemical properties of soils, carbon sequestration, forms of carbon and nitrogen in soils were determined using the following standard laboratory methods:

Particle size distribution was determined by hydrometer method (Gee and Or, 2002).

Bulk density (gcm^{-3}) was determined using core method (Grossman and Reinsch, 2002). This was calculated using: $\ell b = Mws - Mds / Vs$

Where Mws = Mass of wet soil, Mds = mass of oven dried soil, Vs = volume of the oven dried soil which is assumed to be the volume of core given by the formula $V = \pi r^2 h$

Moisture content was determined by gravimetric method (Obi, 1990). This was calculated using the following formulae

$Mc (\%) = Ws - Ds / Ds \times 100$

Where Mc = moisture content, Ws = weight of moist sample, Ds = weight of dried sample.

Total porosity was calculated when the bulk density was known $F = 1 - \ell_b / \ell_s \times 100$

where F = porosity, ℓ_b = bulk density (g/cm^3), ℓ_s = particle density ($2.65\ gcm^{-3}$).

Soil aggregate stability was determined by wet sieving method of Kemper and Rosenau (1986).

Soil pH was determined using 1:2.5 soil : liquid (KCl, water) ratio (Thomas, 1996).

Available P was extracted using Bray-P 2 solution (Olsen and Sommer, 1982) and the quantity of available P in the supernatant solution was determined using the molybdo-vanadate method of Murphy and Riley (1962).

Exchangeable bases were determined by the neutral ammonium acetate (NH_4OAc of pH 7) procedure (Thomas, 1982). Calcium and magnesium were determined by ethylene diamine tetra-acetic acid (EDTA) titration while sodium and potassium were determined using flame photometer.

Total exchangeable acidity (TEA) was determined by the extraction of exchangeable H^+ and Al^{+++} in lN KCl and titrated with 0.05N NaOH. Al^{+++} content of the extract was titrated with 0.05N HCl. H^+ was calculated by subtracting Al^{+++} from TEA (Mclean, 1982)

Effective cation exchange capacity was determined by summation method that is TEB + EA, where TEB is Total exchangeable bases and TEA is Total exchangeable acidity.

3.5 Forms of carbon and carbon sequestration

The soil carbon concentration was fractionated into three major forms namely total, organic and inorganic carbon (Haung and Schoenau, 1996).

Organic carbon was measured by wet digestion method (Nelson and Sommers, 1996).

Total carbon was determined by loss on ignition and wet digestion method (Veres, 2002).

Inorganic carbon was calculated thus: total carbon – organic carbon.

Carbon sequestration (gCm^{-2}**)** was calculated using the method of Batjes (1996)

$BD\ (gcm^{-3}) \times OC\ (gkg^{-1}) \times \text{thickness of horizon (cm)} \approx \sum Bi \times Ci \times Di$

where Bi is the bulk density of individual layer i (gcm^{-3}), Ci is organic carbon in layer i (gkg^{-1}) and Di is the thickness of this layer (cm). This method was adopted because the study was a pedological (profiling) study with natural horizonation.

3.6 Forms of nitrogen and nitrogen sequestration

Available N was extracted using 2 M KCl in a 1: 5 (soil: water) ratio. NH_4^+ in the supernatant solution was determined by steam distillation of ammonia, using heavy MgO while nitrate nitrogen was determined by Phenol-disulphonic acid colorimeteric method (Bremner and Keeney, 1965, Keeney and Nelson, 1982).

Total nitrogen was determined by Kjeldah digestion method (Bremner and Mulvaney, 1982).

Nitrogen sequestration (gNm^{-2}**) =** $\sum Di \times Bi \times TNi$ where D = depth, B = bulk density and TN = total nitrogen (He *et al*., 2012).

3.7 Soil classification

Soil classification was done in accordance with the criteria outlined in Soil Survey Staff (2003). Taxonomic classification was done to Subgroup level. The soil classes derived from soil taxonomic classification of the USDA were correlated with the World Reference Base of the FAO (1998).

3.8 Data analysis

Soil data were subjected to analysis of variance (ANOVA) to test differences in soil properties, soil carbon and nitrogen forms and sequestration across soils of different parent materials and land use types. For statistically different parameters ($p < 0.001, 0.01, 0.05$), means were separated using Least Significant Difference (LSD). The major parameter influencing grouping, sequestering and activities of these soils were identified using multiple regression analyse. Multiple linear regression model was used to describe the effects of independent variables on dependent variables described as follows: $Y = b0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$, where Y = the dependent variable, $x_1, \ldots x_4$ = independent variables, $b_1, \ldots b_4$ = coefficients that describe the effect of the independent variables on dependent variable, b = the value Y is predicted to have when all independent variables are equal to 0 (Shaw and Wheeler, 1996). Correlation analyses were conducted to detect the functional relationships among soil variables while the vertical variation (profile distribution) of soil properties were determined using coefficient of variation. The coefficient of variation was ranked according to the procedure of Wilding, (1985) where $Cv \leq 15\%$ = low variation, $Cv > 15 \leq 35\%$ = moderate variation, $Cv > 35\%$ = high variation. GenStat statistical software (Payne *et al*., 2007) and SPSS statistical software version 17.0 (SPSS, 2009) were used for statistical analyses.

CHAPTER FOUR

Results and Discussion

4.1 Morphological Properties of the Soils

The details of the land use history of the areas and morphological properties of soils are presented in Tables 4.1 - 4.4. Table 4.1 showed the kind of farming activities and common tree and crop species present in each land use type. Soils developed on different parent materials under different land use types had varying colour matrix ranges (Tables 4.2 – 4.4). The colour of soils derived from Falsebedded Sandstones ranged from very dark reddish brown (5YR 2/4, 5YR 4/8 moist) at the surface horizons to orange (2.5YR 7/6, 2.5YR 7/8, 2.5YR 6/6 moist) down the profile in forest land (Table 4.2a), reddish brown (5YR 4/6, 5YR 3/6, moist) at the surface horizons to red (10R 5/8, 10YR,4/6 moist) down the profile in fallow (Table 4.2b) and dark reddish brown to reddish orange in cultivated land (Table 4.2c). In soils derived from Shale, soil colour ranged from dark reddish brown (2.5 YR 3/3 , 2.5 YR, 5/8 moist) to dark red (10 R ¾ , 10 R 5/8, 10 R 5/3moist) in forest land (Table 4.3a), dark reddish brown (5 YR ¾ , 5YR 2/3 moist) to orange (2.5 YR 6/6 moist) in fallow land (Table 4.3b) and very dark reddish brown (2.5 YR 2/2) to brownish gray (5 YR 6/1moist) in cultivated land (Table 4.3c). In soils derived from the Coastal plain sands, colour ranged from dark reddish gray (7.5 YR 3/1 moist) to light red (2.5 YR 6/8 moist) in forest (Table 4.4a), dark reddish brown (5 YR 2/3 moist) to red (2.5 YR 4/8 moist) in fallow (Table 4.4b) and reddish brown to red in cultivated land (Table 4.4c). However, in Shale-derived soils, most horizons especially the elluvial and illuvial horizons had more of grayish colour compared to similar horizons in Falsebedded sandstone and Coastal plain sands across all the different land uses investigated. This could be attributed to variations in parent materials and land use history of the areas.

Generally, soils were darker and browner on the surface (epipedons) and redder down the profile irrespective of the parent materials and land use types. However, soils of the forest were darker across all the parent materials studied compared to soils of the fallow and cultivated lands. The dark colour observed at the surface horizons and in forest soils could be attributed to significantly higher organic matter contents of these soils and the drainage conditions of the horizons. This result confirms those of Ahukaemere *et al.*, (2012), Onweremadu and Oti, (2005). Apart from soil fertility evaluation, soil color can be used to classify soil (Soil Survey Staff, 2003, FAO (WRB), 2006) and assess soil drainage (Foth, 1984). The effect of usually dark brown or black soil organic matter on soil color is important not only for soil classification purposes, but also for ensuring good thermal properties, which in turn contribute to soil warming and promote biological processes (Schulze *et al*., 1993). Soil colour is a cheap indicator of soil quality which provides valuable clues to the nature of other soil properties and conditions. Generally good soil conditions are associated with dark brown colours near the soil surface, which is associated with relatively high organic matter levels, good soil aggregation and high nutrient levels (Onweremadu and Oti 2005).

Table 4.1. : Location, parent material and Land use history of the different sites used for the study

Location	Parent material	Land use	Land use history
Umuagwo,Ohaji (5^{0} 19^{1} 29.4^{11} N, 6^{0} 58^{1} 32.6^{11} E)	Coastal plain sand	Forest	23 years secondary forest, contained mainly wild perennial plants and grasses such as Oil palm (*Elaeis guineensis*), Banana (*Musa sapientum*), Oil been tree (*Pentaclethra macrophylla*), bush mango (*Irvingia gabonensis*), Elephant grass (*Pennisetum purpurem*), Giant star grass (*Cynodon plectostachyus*).
Umuagwo,Ohaji (5^{0} 29^{1} 40.4^{11} N, 6^{0} 34^{1} 32.6^{11} E)	Coastal plain sand	Fallow	Imo State Polytechnic Research plot, practiced conventional tillage for 5 years, allowed to grow fallow for 7 years. Contained different plant species including wild legumes such as *calapogonum mucunoid*, *centrosema pubiscense*. Goat-weed (*Sida acuta*),
Umuagwo,Ohaji (5^{0} 21^{1} 29.4^{11} N, 6^{0} 32^{1} 41.6^{11} E)	Coastal plain sand	Cultivated land	Imo State Polytechnic Research plot, Conventionally tilled with farm machines, continuously-cropped with *capsicum* spp (green and hot pepper) and *Albemoschus esculentum* (okro) as intercrop, fertilized with NPK fertilizer and single phosphate fertilizer.
Umulolo,Okigwe (5^{0} 52^{1} 42.6^{11} N, 7^{0} 18^{1} 52.7^{11} E)	Falsebedded Sandstone	Forest	21 years secondary forest, contained mainly wild perennial plants such as *Tectona grandis (*Teak*)*,
Umulolo,Okigwe (5^{0} 52^{1} 48.1^{11} N, 7^{0} 18^{1} 27.2^{11} E)	Falsebedded Sandstone	Fallow	Adjacent land near the forest, fallowed for 8 years, contained *Chromolaeana odorata*, elephant grass *(Pennisetum purpueru)*, palm tree (*Elaeise guineensis*) and wild legumes.
Umulolo,Okigwe (5^{0} 52^{1} 20.5^{11} N, 7^{0} 17^{1} 51.7^{11} E)	Falsebedded Sandstone	Cultivated land	NIHORT Research farm, Conventionally tilled with farm machines, fertilized with inorganic fertilizer like NPK, unmulched, mixed cropping containing pumpkin, *Albemoschus esculentum* (okro) and egg plant (*Solanium* spp.), tomatoes (*Lycopersicum esclentum*).
Itumbuzor,Bende (5^{0} 53^{1} 28.5^{11} N, 7^{0} 18^{1} 39.2^{11} E)	Shale	Forest	21 years secondary forest, contained mainly perennial plants such as cocoa, Oil been tree (*Pentaclethra macrophylla*),
Itumbuzor,Bende (5^{0} 42^{1} 38.5^{11} N, 7^{0} 18^{1} 39.2^{11} E)	Shale	Fallow	Adjacent land near the forest, fallowed for 8 years, contained goat weed (*Ageratum conyzoides*), *Chromolaeana odorata, Panicum maximu*, and wild legumes.
Itumbuzor,Bende (5^{0} 55^{1} 39.5^{11} N, 7^{0} 69^{1} 07.2^{11} E)	Shale	Cultivated land	Conventionally tilled with traditional hoe, unmulched, burning of plant debris, mixed cropping containing fluted pumpkin (*Telfaria occidentalis*), *Albemoschus esculentum* (okro), *Zea mays* (maize), *Discorea rotundata* (yam)

Source: Field survey, (2010)

Table 4.2a:Morphological Properties Of Forest Soils Derived From Falsebedded Sandstones

Depth (cm)	Hor	SoilColour (moist)	Soil structure	Consistency (moist)	(dry)	Root composition	TC
			Profile 1				
0-1	Oe	VDRB 5 YR 2/4	2, f gr.	Very friable	Loose	Many coarse woody roots	LS
1-3	Oa	DRB 5 YR ¾	2, me, gr.	Very friable	Ssoft	Many coarse woody roots	LS
3-9	A	DRB 5 YR 3/6	2, f gr.	Friable	Soft	Many coarse woody roots	LS
9-40	AB	RB 2.5 YR 4/6	3, v c., sb.	Firm	Hard	Many coarse woody roots	LS
40-89	Bt1	Orange 2.5 YR 6/8	3, me, ab.	Very firm	Very hard	Very Few coarse woody roots	LS
89-160	Bt2	Orange 2.5 YR 7/6	3, me, sb.	Very firm	Very hard	Very Few coarse roots	LS
			Profile 2				
0-2	Oe	VDB 5 YR 4/8	2, f gr.	Very friable	Soft	Few fibrous roots	LS
2-4	Oa	DRG 2.5 YR 3/1	2, me, gr.	Friable	Soft	Many coarse woody roots	LS
4-13	A	DRB 2.5 YR ¾	2, me, gr.	Firm	Soft	Many coarse woody roots	SL
13-49	AB	BB 2.5 YR 4/8	2, me, sb.	Firm	Hard	Few coarse woody roots	LS
49-91	Bt1	Orange 2.5 YR 6/6	3, me, sb.	Very firm	Hard	Few coarse woody roots	SL
91-158	Bt2	Orange 2.5 YR 7/8	2, me, sb.	Very firm	Hard	Very Few coarse woody roots	SL
			Profile 3				
0-3	Oa	DRG 2.5 YR 3/1	2, me, gr.	Very friable	Soft	few fibrous roots	LS
3-15	A	DRB 2.5 YR ¾	2, me, gr.	Friable	Slightly hard	Many coarse woody roots	SL
15-60	AB	BB 2.5 YR 4/8	3,, c sb.	Very firm	very hard	Few coarse woody roots	SL
60-131	Bt1	Orange 2.5 YR 6/6	3, me, sb.	Very firm	Very hard	Very Few coarse woody roots	SL

Hor(Horizon): Oe = Hemic horizon, Oa = Sapric,**TC (Textural Class)**: LS = loamy sand, SL = sandy loam, **Munsell notation:** VDRB = Very dark reddish brown, DRB = Dark reddish brown, RB = Reddish brown, VDB = Very dark brown, DRG = Dark reddish gray, BB = Bright brown, **Structure**: 2 = moderate, 3 = Strong, me = medium, V = very , f = fine, gr. = granular, c = coarse, sb = sub-angular blocky, ab = angular blocky, **Root :** Coarse = tap root, fine = fibrous root.

Table 4.2b Morphological Properties of Fallow Soils Derived From Falsebedded Sandstones

Depth (cm)	Hori.	Soil colour (moist)	Soil structure	Consistency (moist)	(dry)	Root composition	TC
			Profile 1				
0-18	A	RB 5YR 4/6	2, me, gr.	Friable	Slightly hard	Many fibrous roots	LS
18-49	AB	Red 10 R 4/6	2, c ab.	Firm	Hard	Many medium woody roots	LS
49-98	Bt1	Red 10 R 4/8	2, c sb.	Very firm	Very hard	Few medium woody roots	LS
98-145	Bt2	Red 10 R 5/8	2, c sb.	Very firm	Very hard	Very Few medium woody roots	LS
			Profile 2				
0-9	A	RB 5 YR 4/6	2, me, sb.	Firm	Slightly hard	Many very fibrous roots	LS
9-35	AB	Red 10 R 4/6	2, me, sb.	Firm	Slightly hard	Many mediumwoody roots	SL
35-76	Bt1	Red 10 R 4/8	2, me, sb.	Very firm	Hard	Few medium woody roots	LS
76-110	Bt2	Red 10 R 5/8	2, me, sb.	Very firm	Hard	No root	SL
			Profile 3				
0-15	A	DRB 5 YR 3/6	2, v fgr.	Friable	Soft	Many very fibrous roots	LS
15-33	AB	RB 5 YR 4/6	2, v c ab.	Firm	Hard	Many medium woody roots	LS
33-98	Bt1	RB 2.5 YR 3/6	3, c sb.	Very firm	Hard	Very Few medium woody roots	LS
98-130	Bt2	Red 10 YR 4/6	3, v c sb.	Very firm	Hard	No roots	LS

TC (Textural Class): LS = Loamy sand, SL = Sandy loam, **Munsell notation:** RB = Reddish brown, DRB = Dark reddish brown, **Structure:** 2 = moderate, 3 = strong, me = medium, V = very , f = fine, gr. = granular, c = coarse, sb = sub-angular blocky, ab = angular blocky, **Root :** medium = secondary root.

Table 4.2c:Morphological Properties of Cultivated Soils Derived From Falsebedded Sandstones

Depth (cm)	Hor	Soil colour (moist)	Soil structure	Consistency moist	Dry	Root composition	TC
Profile 1							
0-9	Ap	DRB 10 R ¾	2, c sb.	Very Friable	Soft	Many very fibrous roots	LS
9-26	AB	DR 7.5 R ¾	2, vc, ab.	Friable	Soft	Very Few fibrous roots	LS
26-80	Bt1	Dusky Red7.5 R 4/4	3, v c, sb	Firm	Very hard	No root	LS
80-103	Bt2	Red 10 R 4/8	3, v c ab.	Very firm	Very hard	No root	LS
103-180	Bt3	Red 10 R 5/8	3, v c ab.	Very firm	Very hard	No root	LS
Profile 2							
0-9	Ap	DRB 5 YR 3/3	2 f gr.	Very Friable	Soft	Many very fibrous roots	LS
9-29	AB	DRB 5 YR 3/6	2, c ab.	Friable	Soft	Very few fibrous roots	LS
29-50	Bt1	DR 7.5 R ¾	2, v c sb.	Firm	Slightly hard	No root	LS
50-79	Bt2	Red 10 R 5/8	2, v c, sb	Firm	Slightly hard	No root	LS
79-120	Bt3	Red 10 R 6/6	3, v c, ab.	Very firm	Very hard	No root	SL
120-180	Bt4	RO 10 R 6/8	3,v c, ab.	Very firm	Very hard	No root	SL
Profile 3							
0-17	Ap	DRB 5 YR ¾	2,c sb.	Very Friable	Soft	Many very fibrous roots	LS
17-29	AB	RB 10 R 4/4	2,c sb.	Friable	Slightly hard	Very few fibrous roots	LS
29-46	Bt1	Red 10 R 4/8	2, me, sb.	Firm	Slightly hard	No root	LS
46-98	Bt2	Red 10 R 5/8	3, c ab	Very firm	Very hard	No root	LS
98-178	Bt3	RO 10 R 6/8	3, v c ab.	Very firm	Very hard	No root	LS

TC (Textural Class): LS = Loamy sand, SL = Sandy loam, **Munsell notation:** RB = Reddish brown, DRB = Dark reddish brown, DR = Dark red, RO = Reddish orange, **Structure:** 2 = moderate, 3 = strong, me = medium, V = very , f = fine, gr. = granular, c = coarse, sb = sub-angular blocky, ab = angular blocky.

The consistence of the soils varied from very friable when moist and loose when dry at the surface horizons to very firm when moist and very hard when dry down the profile in soils derived from Coastal plain sands (Tables 4.4a - 4.4c) and Falsebedded sandstones (Tables 4.2a - 4.2c). In soils derived from Shale, soil consistency ranged from friable when moist and soft when dry at the surface horizons to very firm when moist and extremely hard when dry down the profile (Tables 4.3a - 4.3c). From the result, soils derived from Shale parent material had firmer and harder consistency than those of Coastal plain sands and Falsebedded sandstones, revealing the influence of parent material on soil properties. However, from the results, it was also ascertained that the firmness and hardness of the soils increased down the profiles across the soils investigated irrespective of the land use types and parent materials. This could be attributed to the clay contents of the sub-surface horizons. In addition to this, the surface horizons were well drained in all the soils indicating the preponderance of macro pores in these horizons, which could be attributed to high total porosity recorded in the surface horizons. Good drainage is a result of abundance of macro pores in soils (Barker *et al*., 2004).

The structures of the soils ranged from weak, very fine granular to strong, very coarse angular and sub-angular blocky (Tables 4.2a – 4.4c) across the soils formed from the varying parent materials studied. Granular structures were observed in the surface horizons of most of the pedons. This agrees with the findings of Anon. (2006) that granular structures are found mainly in A horizons formed by organic carbon. Soils derived from Shale parent material had more of moderate to coarse blocky structural units (Table 4.3a -4.3c) while those of Coastal plain sands were mostly granular in structure (tables 4.4a – 4.4c). However, the epipedons had structures that are susceptible to erosion compared to the sub-surface horizons. Soil erodibility – susceptibility of the soil to erosion is mainly a function of soil structural stability. Soil erodibility and the separation of soil particles are reduced to the barest minimum where soil structural stability is high (Anon. 2006). In the presence of coarse soil structural units, runoff and sediment losses are generally reduced (Deizman *et al*., 1987). According to Diaz-Zorita *et al*., (2002), soil structure exerts a strong influence upon consistency and total porosity.

Table 4.3a Morphological Properties of Forest Soils Derived From Shale

Depth (cm)	Ho	Soil colour (moist)	Soil structure	Consistence		Root composition	TC
				Moist	Dry		
			Profile 1				
0-5	Oa	DRB 2.5 YR 3/3	2, f gr.	Friable	Soft	Dead and partially decomposed debria, few medium and coarse woody roots	SL
5-19	A	Brown 7.5 YR 4/6	2, f gr.	Friable	Soft	Few coarse woody roots	L
19-56	AB	DRB 5 YR 3/6	2, me, sb.	Firm	Hard	Few coarse woody roots	CL
56-98	Bt1	Red 10 R 4/6	2, me, sb.	Firm	Hard	Very few coarse woody roots	SiCL
98-142	Bt2	Red 10 R 4/8	2, v c, ab.	Very firm	Very hard	Very few coarse woody roots	SiCL
142-189	Bss	RB 10 R 5/3	2, c, sb.	Very firm	Very hard	No root	SiC
			Profile 2				
0-3	Oa	VDB 7.5 YR 2/3	1, v f gr.	Friable	Soft	Dead and partially decomposed debria, many medium and few coarse woody roots	L
3-10	A	DRB 5 YR ¾	2, v f gr.	Friable	Slightly hard	Few medium and coarse woodyroots	L
10-36	AB	GR 10 R 4/2	1, v f sb.	Firm	Hard	Few coarse woody roots	SiCL
36-60	Bt1	GR 10 R 4/2	2, me, sb	Firm	Hard	Very few coarse woody roots	SiC
60-110	Bt2	DR 7.5 R 4/4	3, c, ab.	Very firm	Very hard	Very few coarse woody roots	SiC
110-185	Bss	Red 10 R 5/8	3, v c sb.	Very firm	Very hard	No roots	C
			Profile 3				
0-3	Oa	DRB 2.5 YR 5/8	2, f gr	Friable	Soft	Dead and partially decomposed debria, many medium and few coarse woody roots	L
3-14	A	DB 7.5 YR ¾	1, f gr	firm	Slightly hard	Very Few medium and coarse woody roots	L
14-50	AB	Dusky Red7.5YR 6/6	2, f sb	Firm	Hard	Few coarse woody roots	SiCL
50-89	Bt1	Dull RB 5 YR 4/2	2, me ab	Firm	Hard	Very few coarse woody roots	SiCL
9-107	Bt2	Red 7.5 R 4/8	2, me sb	Very firm	Very hard	Very few coarse woody roots	C
107-189	Bss	DR 10 R ¾	2, v c sb	Very firm	Very hard	No roots	C

Hor(Horizon): Oe = Hemic horizon, Oa = Sapric, **TC (Textural class):** SL = Sandy loam, L = Loam, SiCL = Silt clay loam, SiC = Silt clay, C = Clay, **Munsell notation:** GR = Grayish red, VDB = Very dark brown, RB = Reddish brown, DRB = Dark reddish brown, DR = Dark red, DB = Dark brown, TC = Textural Class, **Structure:** 1 = weak, 2 = moderate, 3 = strong, me = medium, V = very , f = fine, gr. = granular, c = coarse, sb = sub-angular blocky, ab = angular blocky, **Root :** Coarse = tap root, Medium = secondary root.

Table 4.3b: Morphological Properties of Fallow Soils Derived From Shale

Depth (cm)	Hor	Soil colour (moist)	Soil structure	Consistence		Root composition	TC
				moist	dry		
			Profile 1				
0-14	A	DRB 5 YR ¾	1, v f gr.	Fri	Soft	Many fibrous and few medium woody roots	SL
14-37	AB	RB 10 R 5/3	1, me, sb.	Firm	Slightly hard	Many medium woody roots	L
37-58	Bt1	LOG 5Y 5/3	2, me, sb.	Firm	Hard	Few medium woody roots	CL
58-100	Bt2	Dull RB 7.5 R 4/2	2, me, sb.	Firm	Hard	Very few coarse woody roots	SiCL
100-148	Bt3	BRB 5 YR 5/8	2, v c sb.	Very firm	Very hard	Very few coarse woody roots	SiC
148-186	Bt4	RB 10 R 5/4	2, v c sb.	Very firm	Very hard	No roots	C
			Profile 2				
0-12	A	DB 7.5 YR 3/2	1, f gr.	Fri	Soft	Many fibrous and medium roots	SL
12-38	AB	DRB 7.5 R 2/3	1, me, sb.	Firm	Hard	Many medium woody roots	L
38-57	Bt1	GR 2.5 YR 4/2	2, me, sb.	Firm	Hard	Few medium woody roots	SiC
57-145	Bt2	DRB 2.5 YR 3/6	2,me, ab.	Very firm	Very hard	Very few coarse woody roots	CL
145-185	Bt3	BB 2.5YR5/6	3, v c sb.	Very firm	Very hard	No roots	CL
			Profile 3				
0-11	A	DRB 5 YR 2/3	2, me, gr.	Friable	Soft	Many medium woody roots	SL
11-44	AB	GR 10.5 R 4/2	2, me, sb.	Firm	Hard	Few medium woody roots	L
44-95	Bt1	RB 2.5 YR 2/6	2, me, sb.	Very firm	Very hard	Very few coarse woody roots	SCL
95-123	Bt2	BRB 5 YR 5/6	3, c ab.	Very firm	Very hard	No roots	C
123-180	Bt3	Orange 2.5YR 6/6	3, c ab.	Very firm	Very hard	No roots	C

TC (Textural Class): SL = sandy loam, SiCL = silt clay loam, SCL = Sandy clay loam, SiC = silt clay, C = clay, CL = clay loam, **Munsell notation:** BRB = bright reddish brown, LOG = light olive gray, GR = Grayish red, RB = Reddish brown, DRB = Dark reddish brown, DR = Dark red, DB = Dark brown, BB = Bright brown, **Structure:**1 = weak, 2 = moderate, 3 = strong, me = medium, V = very , f = fine, gr. = granular, c = coarse, sb = sub-angular blocky, ab = angular blocky. **Root :** Coarse = tap root, Medium = secondary root.

Table 4.3c: Morphological Properties of Cultivated Soils Derived From Shale

Depth (cm)	Hor	Soil colour (moist)	Soil structure	Consistence moist	dry	Root composition	TC
			Profile 1				
0-12	Ap	VDRB 2.5 YR 2/2	2, f gr.	Fri	Soft	Many very fibrous roots	SL
12-66	AB	RB 10 R 4/4	2, f gr.	Firm	Hard	Few fibrous roots	SiCL
66-104	Bt1	BG 5 YR 6/4	2, f sb.	Firm	Hard	No roots	SCL
104-143	Bt2	RB 5 YR 4/6	2, me, sb.	Very firm	Very hard	No roots	C
143-180	BSS	BG 5 YR 6/1	2, me, ab.	Very firm	Very hard	No roots	C
			Profile 2				
0-9	Ap	GR 10 R 4/2	2, v f gr.	Fri	Soft	Many very fibrous roots	SL
9-70	AB	RB 7.5 R 4/2	2, f gr.	Firm	Hard	Few fine roots	L
70-89	Bt1	LOG 5 Y6/2	2, c, sb.	Firm	Hard	No roots	SCL
89-117	Bt2	Dull RB 7.5 R 5/3	2, v c sb.	Very firm	Very h	No roots	C
117-180	BSS	BR (7.5 R 4/6)	2, v c sb.	Very firm	Very hard	No roots	C
			Profile 3				
0-9	Ap	DRB 2.5 YR 2/3	2, v f gr.	friable	Soft	Many very fibrous roots	SL
9-68	AB	DuskyRed 7.5 R 4/4	2, f gr.	Firm	Hard	Few fibrous roots	SCL
68-105	Bt1	RB 10 R 5/3	2, c, ab.	Firm	Hard	No roots	SiC
105-133	Bt2	DRB 2.5 YR ¾	2, v c ab.	Very firm	Extremely hard	No roots	SiC
133-185	BSS	RB10 R 4/4	2, v c ab.	Very firm	Extremely hard	No roots	C

TC (Textural Class): SL = sandy loam, SiCL = Silt clay loam, SCL = Sandy clay loam, SiC = Silt clay, C = Clay, CL = Clay loam, L = Loam, **Munsell notation:** BRB = Bright reddish brown, DRB = Dark reddish brown, RB = Reddish brown , DB = Dark brown, BG = Brownish gray, GR = Grayish red, LOG = Light orange gray, **Structure:** 2 = moderate, me = medium, V = very , f = fine, gr. = granular, c = coarse, sb = sub-angular blocky, ab = angular blocky.

The root composition of the soils showed presence of very fibrous and medium woody (secondary) roots at the surface horizons of all the profiles under fallow and cultivated land use types across the varying parent materials (Table 4.2a - 4.4c). No root was seen at the deepest horizons of these land use types. The forest lands contained more coarse woody (tap) roots than other land use types, which could be due to the presence of perennial plants and trees - an important attribute of forest. Also the Oe (hemic) and Oa (sapric) horizons of the forest (forest floor) contained dead and partially decomposed debris which is a reflection of high organic carbon recorded in these horizons (Tables 4.2a, 4.3a, 4.4a). This result is in agreement with that of Awotoye *et al*., (2011). Oriowo (1989) reported abundance of fibrous roots in 0 – 20 cm depth in a regrowth forest and this possibily enhances good biological and chemical characteristics of soils such.

Soil texture ranged from sand, loamy sand to sandy loam in soils derived from Coastal plain sand and Falsebedded sandstone; loam, sandy clay loam, silt clay loam to clay in Shale derived soils (Tables 4.2a - 4.4c). Generally, soils formed from Shale parent material were more clayey and contained finer soil particles when compared with those of Falsebedded sandstone and Coastal plain sand. The soil texture reflect the nature of the parent material from which the soils where developed and the drainage pattern of the area (Oguike and Mbagwu, 2009). Moreover, the textural classes across the land uses of the Falsebedded Sandstone and Coastal plain sand were majorly sandy loam and loamy sand indicating the similarity of parent materials (Foth, 1990). Sandiness of the soils of Falsebedded sandstone and Coastal plain sand indicates observable low moisture content of these soils which may result to moisture stress. In addition to the above, this scenario may encourage rapid leaching of nutrient from the soils beyond the rooting zones of the planted crops. However, the coarse nature of these soils can in turn encourage soil erodibility on exposure to high rainfall through reduced fallow period and the conversion of forest to cultivated land, leading to soil degradation (Osuji *et al*., 2002). From the results of the morphological properties of soils studied, soils differed in their morphological attributes which could be due to variations in parent material, land use history (Table 4.1), climate (Appendix 5) and landscape position. Akamigbo, (1999a) and Malgwi *et al* (2000) reported that land use type and parent material alter soil properties which influence the overall performance of soil.

Table 4.4a: Morphological Properties of Forest Soils Derived from Coastal plain sand

Depth (cm)	Hor	Soil colour (moist)	Soil structure	Consistence (moist)	(dry)	Root composition	TC
			Profile 1				
0-4	Oe	DRG 7.5 YR 3/1	1, v f gr.	Very friable	Loose	Dead and partially decomposed debria, many medium woody roots	LS
4-18	Oa	DB 10YR 3/3	2, v f gr.	Very friable	Soft	Many medium woody roots	LS
18-48	A	Brown 7.5YR 4/3	2, f gr.	Very friable	Soft	Very few medium woody roots	LS
48-99	AB	Brown 7.5YR 4/3	2,me, sb.	Friable	Soft	Very few coarse woody roots	SL
99-154	Bt1	Strong Brown 7.5YR 5/8	2, f gr.	Friable	Soft	Very few coarse woody roots	SL
154-200	Bt2	Red 2.5YR 5/8	2, me ab.	Firm	Hard	No roots	SL
			Profile 2				
0-5	Oe	VDG 7.5YR3/1	1, f gr.	Very friable	Loose	Dead and partially decomposed debria, many medium woody roots	LS
5-18	Oa	DG 7.5YR 4/1	2, f gr.	Very friable	Soft	Many fine and medium roots	LS
18-47	A	RB 5YR 5/4	2, f gr.	Friable	Soft	Very few coarse roots	LS
47-107	AB	Strong Brown 7.5YR 5/6	2, me gr.	Friable	Soft	Very few coarse roots	SL
107-142	Bt1	Strong Brown 7.5YR 5/6	2,me, sb.	Firm	Soft	No roots	SL
142-200	Bt2	Yellowish Red 5YR 6/8	2,me, sb.	Firm	Hard	No roots	SL
			Profile 3				
0-3	Oe	DRB 2.5YR ¾	2, me gr.	Very friable	Soft	Dead and partially decomposed debria, many medium woody roots	LS
3-21	Oa	DRB 5YR 3/2	2, f gr.	Very friable	Soft	Many medium and few coarse roots	LS
21-48	A	RY 7.5YR 6/6	2, v f gr.	Friable	Soft	Few medium woodyroots	LS
48-103	AB	RB 2.5YR 4/3	2, v f gr.	Firm	Slightly hard	Very few woody roots	SL
103-150	Bt1	Yellowish Red 5YR 5/8	2, f gr.	Firm	Slightly hard	Very few coarse woody roots	SL
150-200	Bt2	Light Red 2.5YR 6/8	2, f gr.	Firm	Slightly hard	No roots	SL

Hor (Horizon): Oe = Hemic horizon, Oa = Sapric, **TC (Textural Class):** LS = Loamy sand, SL = Sandy loam, DRG = Dark reddish gray, DG = Dark gray, RY = Reddish yellow, DRB = Dark reddish brown, RB = Reddish brown, DB = Dark brown, **Structure:** 1 = weak, 2 = moderate, me = medium, V = very , f = fine, gr. = granular, sb = sub-angular blocky, **Root :** Coarse = tap root, Medium = secondary root.

Table 4.4b: Morphological Properties of Fallow Soils Derived from Coastal plain sand

Depth (cm)	Hor	Soil colour (moist)	Soil structure	Consistence		Root composition	TC
				moist	dry		
			Profile 1				
0-11	A	DRB 5YR 2/3	2, f gr.	Very friable	Loose	Few fibrous roots	LS
11-31	AB	DRG 5YR 4/2	2, v f gr.	Very friable	Soft	Many medium woody roots	S
31-86	Bt1	Weak Red 2.5YR 4/2	2,me, sb.	Friable	Slightly hard	Many medium woody roots	LS
86-121	Bt2	Red 2.5YR 4/8	2,me, sb.	Firm	Slightly hard	few medium woody roots	LS
121-154	Bt3	Red 2.5 YR 4/8	2,me, sb.	Firm	Slightly hard	No roots	LS
154-200	Bt4	YellowishRed5YR 5/8	2, v c ab.	Firm	Slightly hard	No roots	LS
			Profile 2				
0-15	A	DRB 5YR 3/2	1, v f gr.	Very friable	Loose	Many fibrous roots	S
15-58	AB	DRB 5YR ¾	1, v f gr.	Very friable	Loose	Many fibrous roots	S
58-105	Bt1	RB 5YR 4/4	2,me, sb.	Friable	Soft	Few medium woody roots	LS
105-150	Bt2	RB 5YR 4/4	2, c ab.	Firm	Slightly hard	Very Few medium roots	SL
150-200	Bt3	Red 2.5YR 5/8	2,me, sb.	Firm	Slightly hard	No roots	SL
			Profile 3				
0-14	A	DB 7.5YR 3/3	2, me gr.	Very friable	Loose	Many fibrous roots	LS
14-56	AB	RB 2.5YR 4/3	2, me gr.	Very friable	Soft	Many fibrous roots	LS
56-97	Bt1	RB 5YR 4/4	2,me, ab.	Friable	Slightly hard	Few medium woody roots	LS
97-149	Bt2	Red 2.5YR 4/6	2,me, sb.	Firm	Slightly hard	Few medium woody roots	SL
149-200	Bt3	Red 2.5YR 4/8	2,me, sb.	Firm	Slightly hard	No roots	SL

TC (Textural Class): LS = Loamy sand, SL = Sandy loam, S = Sand, **Munsell notation:** DRG = Dark reddish gray, DRB = Dark reddish brown, RB = Reddish brown, DB = Dark brown, **Structure:** 1 = weak, 2 = moderate, me = medium, V = very , f = fine, gr. = granular, sb = sub-angular blocky, **Root :** fine = fibrous root, Medium = secondary root.

Table 4.4c: Morphological Properties of Cultivated Soils Derived from Coastal plain sand

Depth (cm)	Hor	Soil colour (moist)	Soil structure	Consistence moist	dry	Root composition	TC
			Profile 1				
0-20	Ap	RB (5 YR 5/2)	2, f gr.	Very friable	Loose	Many very fibrous roots	LS
20-48	AB	StrongBrown7.5YR 4/6	2,me sb.	Friable	Soft	No roots	LS
48-110	Bt1	Yellowish Red 5YR 5/6	2,me sb.	Fri able	Slightly hard	No roots	SL
110-152	Bt2	Light Red 2.5YR 6/8	2,me sb.	Firm	Slightly hard	No roots	SL
152-200	Bt3	Yellowish Red 5YR 5/6	2, c sb.	Firm	Hard	No roots	SL
			Profile 2				
0-28	Ap	RB 5YR 5/3	2, f gr.	Very friable	Lose	Many very fibrous roots	LS
28-49	AB	Yellowish Red 5YR 5/6	2,me gr.	Friable	Soft	No roots	LS
49-114	Bt1	Brown 7.5YR 4/4	2, c ab.	Friable	Slightly hard	No roots	LS
114-150	Bt2	Yellowish Red 5YR 4/6	2, me sb	Firm	Slightly hard	No roots	SL
150-200	Bt3	Red 10R 5/8	2, me sb	Firm	Hard	No roots	SL
			Profile 3				
0-12	Ap	DRB 5YR 3/2	1, f gr.	Very friable	Loose	Many very fibrous roots	S
12-52	AB	RB 5YR 4/4	2, c ab.	Friable	Soft	No roots	LS
52-117	Bt1	Red 2.5YR 4/6	2, me sb	Friable	Soft	No roots	SL
117-158	Bt2	Light Red 2.5YR 6/8	2, me sb	Firm	Slightly hard	No roots	SL
158-200	Bt3	Red 2.5YR 5/8	2, c ab	Very firm	Hard	No roots	SL

TC (Textural Class): LS = Loamy sand, SL = Sandy loam, S = Sand, **Munsell notation:** DRB = Dark reddish brown, RB = Reddish brown, **Structure:** 1 = weak, 2 = moderate, me = medium, V = very , f = fine, c = coarse, gr. = granular, sb = sub-angular blocky, ab = angular blocky.

4.2 Physical Properties of Soils

The physical properties of soils derived from different parent materials are presented in Table 4.5. The average sand and silt contents of soils developed on varying parent materials ranged from 533 - 850 gkg^{-1} and 60 - 142 gkg^{-1} respectively. Soils formed from Coastal plain sands contained significantly higher sand fraction (850 gkg^{-1}) and least quantity of silt (60 gkg^{-1}) than soils of the Falsebedded Sandstones and Shales. Soils developed on Shale parent material contained significantly lower ($p < 0.05$) quantity of sand (533 gkg^{-1}) compared to other soils. Significant variations ($p < 0.05$) were observed in the sand and silt contents of the soils across the parent materials (Table 4.5). The clay contents of the soils varied from 77 gkg^{-1} to 265 gkg^{-1}. Soils developed on Shale parent material had considerably higher proportion of clay than other soils. No significant difference was recorded in the clay contents of Falsebedded sandstone and Coastal plain sand-derived soils. Silt content of soils formed from Shale was intermediate (202 gkg^{-1}) (Table 4.5). However, soil texture has an important role in the assessment of soil characteristics. The uptake capacity of soil, which is an indicator of soil fertility, depends on the texture composition of the soil. According to Loide, (2004), as the percentage of clay particles and colloids contained in the soil increases, the content of plant nutrients bound by these particles and colloids increases as well. Thus the soil's nutrient binding capacity dictates how easily the nutrients not bound by soil particles can be washed out of the soil.

Generally, soils derived from Shale contained finer particle fractions compared to those of Falsebedded sandstone and Coastal plain sand. According to Gray and Murphy (2002), argillaceous rocks such as Shale are predominantly composed of clay particles, and thus give rise to soils with high amounts of clay. The significant differences in clay contents of the dissimilar parent material was further shown in the results of the discriminant analysis (Fig.4.2). The differences in the particle size distribution of the soils reflect the differences in the composition of the parent rocks from which the soils are developed. This finding agrees with those of Irmak *et al*., (2007), Oguike and Mbagwu, (2009), Akamigbo and Asadu, (1983) and Igwe *et al*., (1999). According to Esu, (2005) and Akamigbo, (2001), parent materials influence soil properties and such characteristics among others include clay content.

The soil textural fractions of sand, silt and clay contents ranged from 775 - 782 gkg^{-1}, 136 - 148 gkg^{-1}, and 70 and 82 gkg^{-1} in the three different land uses underlain by Falsebedded sandstone (Table 4.6). In soils of the Coastal plain sand, the proportions of sand, silt and clay ranged from 834 – 871 gkg^{-1}, 44 – 70 gkg^{-1} and 64 – 122 gkg^{-1} across the varying land use types whereas in Shale, sand varied between 518 and 550 gkg^{-1}, while silt and clay ranged between 184 and 212 gkg^{-1}, 256 and 272 gkg^{-1} across all the land use types studied. In soils of the Coastal plain sand, the particle size fractions varied significantly ($p < 0.01$, $p < 0.001$) while no significant variation was recorded in soils developed on Shale and Falsebedded sandstone as indicated in Table 4.6. No significant difference in soil particle fractions under the different land use types in soils formed from Shale and Falsebedded sandstone indicated that the various uses in which lands are subjected to had little or no effect on soil texture. In contrast, with respect to land use types underlain by the Coastal plain sand, however, the mean clay fractions were relatively higher in cultivated land and the least in forest and fallow lands. The clay fractions in cultivated land might be due to the fact that cultivation promotes further weathering processes as it shears and pulverizes the soil and changes the moisture and temperature regimes (Yimer *et al*., 2008, Awdengest *et al*., (2013).

In the most of the profile pits, the clay contents increased with depth, especially in the Bt (argillic) horizons. The low clay content of the surface soils could be associated with the pedogenetic processes especially the movement of clay from the epipedons to the argillic horizons, sorting of soil materials by biological and /or agricultural activities or surface erosion by runoff or combination of these. Chikezie *et al*., (2009), Idoga and Azagaku (2005), Malgwi *et al*., (2000), reviewed that increase in clay content of soil with depth may be due to eluviations - illuviation processes as well as contributions of the underlying geology through weathering. However, the distribution of sand fraction did not follow any particular trend except in soils developed from Shale where the deepest horizons contained the least proportion. Significant interactions ($p < 0.05$) were observed in the Sand and clay contents of the soils studied (Table 4.13). This could be as a result of the physical composition of the parent rocks from which these soils are derived.

The mean silt-clay ratio (SCR) of the soils derived from varying parent materials ranged from 0.80 to 2.13 (Table 4.5). Falsebedded sandstone-derived soils had significantly higher ($p < 0.01$) silt-clay ratio while those of Shale had the least value (Table 4.5). In soils of the different land use types, the silt-clay ratio varied from 1.65 - 2.11, 0.36 - 1.04, 0.70 – 0.84 (Table 4.6). However, considering the different land use types, no significant difference was recorded in the silt-clay ratios of soils formed from Shale and Falsebedded sandstone while those from Coastal plain sand varied significantly ($p < 0.05$). Silt-clay ratio may be used as index of weathering (Van Wambeke, 1962). A low ratio denotes a well weathered soil.

The mean bulk density values of the soils derived from the three parent materials ranged from 1.06 to 1.22 gcm^{-3} (Table 4.5). Significantly higher bulk density values were recorded in soils developed on Coastal plain sand than those of Shale and Falsebedded sandstone, which may be attributed to the sandiness of soils formed from coastal plain sand. However, the bulk density of soils derived from Coastal plain sand was lower than those reported by Oguike and Mbagwu, (2009); Onweremadu (2007b) in some soils of the Coastal plain sand in Southeastern Nigeria. Landon (1991) reported critical value of <1.6-1.8 gcm^{-3} in sandy soils. Similarly, mean bulk density values were below the value quoted as the minimum bulk density at which root-restricting conditions will occur (1.75 – 1.80 Mgm^{-3}) (Soil Survey Staff, 2003). The low bulk density showed that the soils were not compacted (Esu and Ojanuga, 1986). In addition to this, the value of bulk density recorded in Shale-derived soils corroborates with that reported by Chikezie *et al*., (2009) in soils formed from Shale. Low bulk density of soils formed from Shale (1.20 gcm^{-3}) and Falsebedded sandstone (1.06 gcm^{-3}) could be attributed to the organic matter contents (30.4, 38.1 gkg^{-1}) of the soils. The significant influence of organic matter and clay on bulk density has been reported by several authors (Akamigbo, (1999b), Chikezie *et al*., (2009). Furthermore, the lowest bulk density found in soils of the Falsebedded sandstone (1.06 gcm^{-3}) indicates that the soils are not compacted and have more pore spaces which is indicated by high porosity found in these soils (Tables 4.5, 4.6).

Table 4.5 : Physical Properties of Soils derived from Different Parent Materials

Parent material	**Sand (gkg^{-1})**	**Silt (gkg^{-1})**	**Clay (gkg^{-1})**	**SCR**	**BD (gcm^{-3})**	**MC (%)**	**TP (%)**	**MWD (mm)**	**WSA (%)**
Shale	533.10	202.20	264.70	0.80	1.20	12.49	54.16	1.35	29.23
CPS	850.20	59.90	90.20	0.88	1.22	9.74	53.89	1.16	17.11
FBS	778.80	141.70	77.30	2.13	1.06	9.09	59.90	0.92	19.38
LSD	45.29***	27.48***	27.39***	0.344***	0.046***	1.322***	1.847***	0.192***	2.406***

CPS = Coastal plain sand, FBS = Falsebedded sandstone, BD = Bulk density, SCR = Silt-clay ratio, MC = moisture content, TP = total porosity, MWD = mean weight diameter, WSA = water stable aggregate.

LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant,

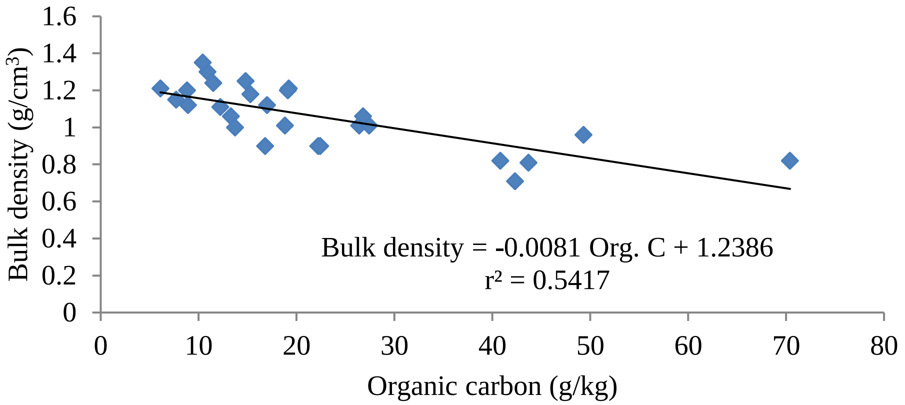
Table 4.6: Physical Properties of Soils of the different Land Use Types

Land uses	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	SCR	BD (gcm^{-3})	TP (%)	MC (%)	WSA (%)	MWD (mm)
					Falsebedded Sandstone				
Cl	781.80	148.00	70.20	2.11	1.12	57.78	8.26	12.58	0.46
Forest	775.10	141.30	79.10	1.79	0.93	64.45	10.02	27.37	1.48
Fallow	779.60	135.80	82.40	1.65	1.13	57.49	8.97	18.20	0.81
LSD	NS	NS	NS	NS	0.08***	2.83***	1.21***	2.92***	0.19***
					Coastal plain sand				
Cl	833.60	44.00	122.40	0.36	1.19	54.87	8.88	11.71	0.95
Forest	845.80	69.60	84.70	0.82	1.09	58.91	9.29	23.17	1.45
Fallow	871.30	66.20	63.50	1.04	1.38	47.89	11.20	16.43	1.07
LSD	19.78**	15.96**	20.26***	0.57*	0.074***	2.64***	1.43*	4.83**	NS
					Shale				
Cl	517.00	210.00	272.40	0.77	1.29	51.62	9.83	19.00	0.79
Forest	532.20	212.00	255.80.	0.84	1.08	60.89	14.80	41.40	2.07
Fallow	550.00	184.20	265.80	0.70	1.28	49.99	12.84	27.30	1.18
LSD	NS	NS	NS	NS	0.09***	4.036***	1.49***	5.27***	0.306***

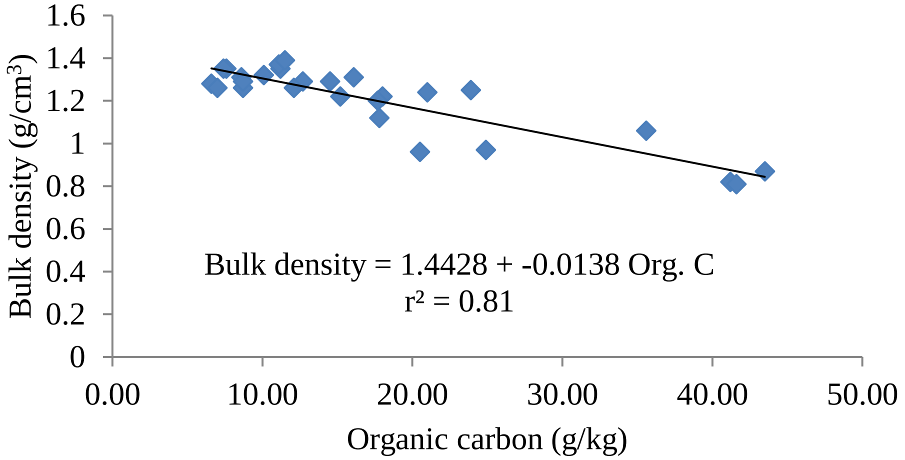
Cl = Cultivated land, BD = Bulk density, SCR = Silt-clay ratio, MC = moisture content, TP = total porosity, MWD = mean weight diameter, WSA = water stable aggregate.

LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant.

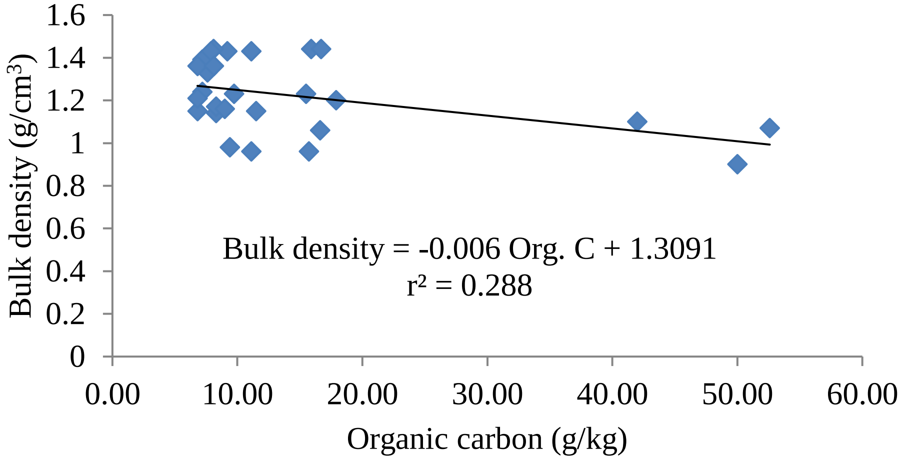
In soils under the different land use types, mean bulk density values varied from 0.93 gcm^{-3} in forest soils to 1.13 gcm^{-3} in fallow soils of the Falsebedded sandstone, 1.09 in forest to 1.38 gcm^{-3} in fallow soils of the Coastal plain sand, 1.03 gcm^{-3} in forest to 1.29 gcm^{-3} in cultivated soils of the Shale (Table 4.6). From the results, forest soils had the least bulk density compared to other soils. This finding agrees with the reports of Michel *et al*., (2010); Islam and Weil (2000); Yihenew and Getachew, (2013); King and Camp, (1994) who found that bulk density increased from natural forest to non forested land. Low bulk density of forest soils may be a reflection of high organic matter contents of the soils. Yihenew and Getachew, (2013) further reported that in forest land, there was relatively higher organic matter making the soil loose, porous and well-aggregated thus reducing the bulk density. Significant negative correlation was obtained between bulk density and organic carbon ($r = -0.900$, $r = -0.537$, $r = -0.736$) ($p < 0.001$) (Figs. 4.1a-4.1c), bulk density and total nitrogen ($r = -0.820^{***}$, $r = -0.332^{**}$, $r = -0.721^{***}$) (Table 4.11). Contrary to expectation, in soils developed on Shale and Falsebedded sandstone, fallow and cultivated lands did not show significant differences in their bulk density values while in those formed from Coastal plain sand, cultivated soils had significantly ($p < 0.001$) lower bulk density than those of fallow land. However, this may be due to variation in land use history and land management practices (Table 4.1). According to information obtained by the land users in the area investigated, the fallow land was under cultivation for five years with heavy machines before it was abandoned. In individual profile, bulk density generally increased down the pit irrespective of the land use types **(**Figs 4.2 – 4.4). Ahukaemere *et al*., (2012) showed that reduced bulk density on the soil surface was directly related to increased organic matter which played a significant role in reducing soil compaction. Concisely, bulk density values were lower than the critical limits for root restriction (1.75 – 1.85 gcm^{-3}) (Soil Survey Staff, 1996) indicating the potential of the soil to support crop production. Low bulk density is beneficial to root activity, water infiltration into the soil, and overall growth of crops (Attah, 2013). Parent material x land use, parent material x profile pits ($p < 0.01$), parent material x land use x profile pit ($p < 0.05$) had significant interactions (Table 4.11) indicating differences in the bulk density values of the soils; and could be as a result of variation in parent material and land use systems and soil management practices.



(a) Falsebedded Sandstone -derived soils



(b) Shale -derived soils



(c) Coastal Plain Sand -derived soils

Figures (4.1a - 4.1c): Relationship between bulk density and organic carbon in soils derived from three different parent materials

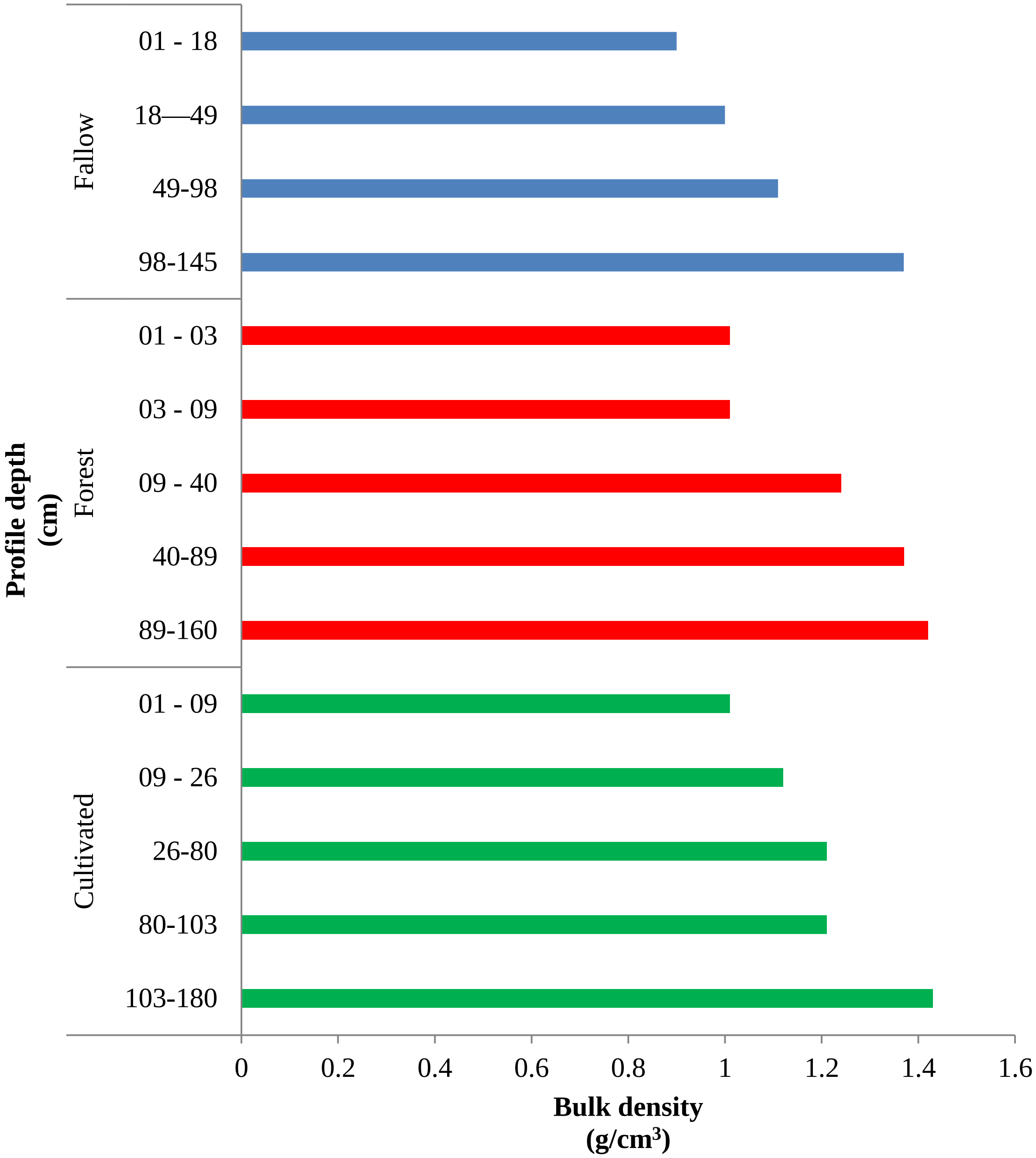


Fig 4.2. Effects of horizon depth (cm) on bulk density (g/cm^3) in soils derived from Falsebedded Sandstone under different land use types.

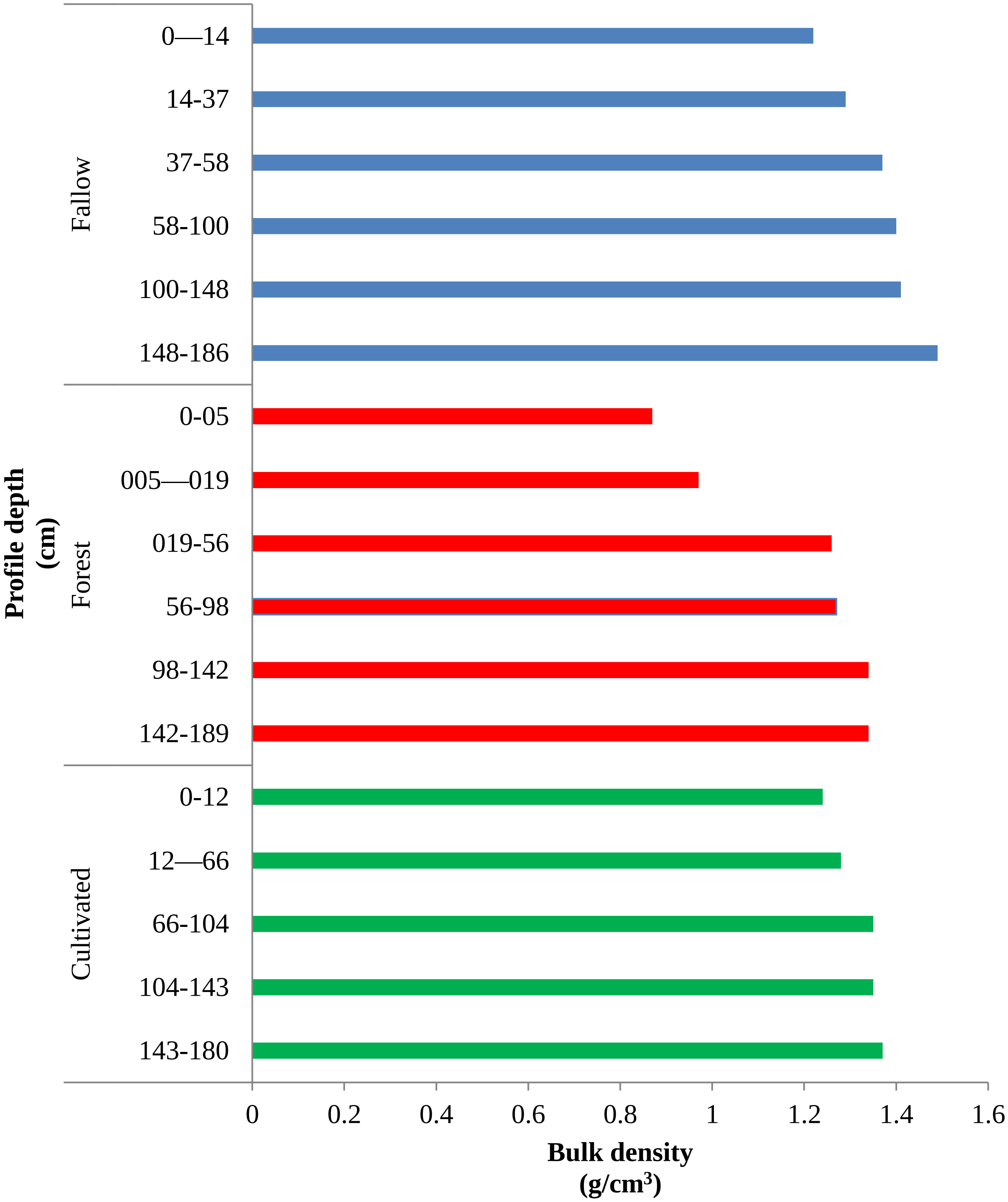


Fig 4.3. Effects of horizon depth (cm) on bulk density (g/cm^3) in soils derived from Shale under different land use types.

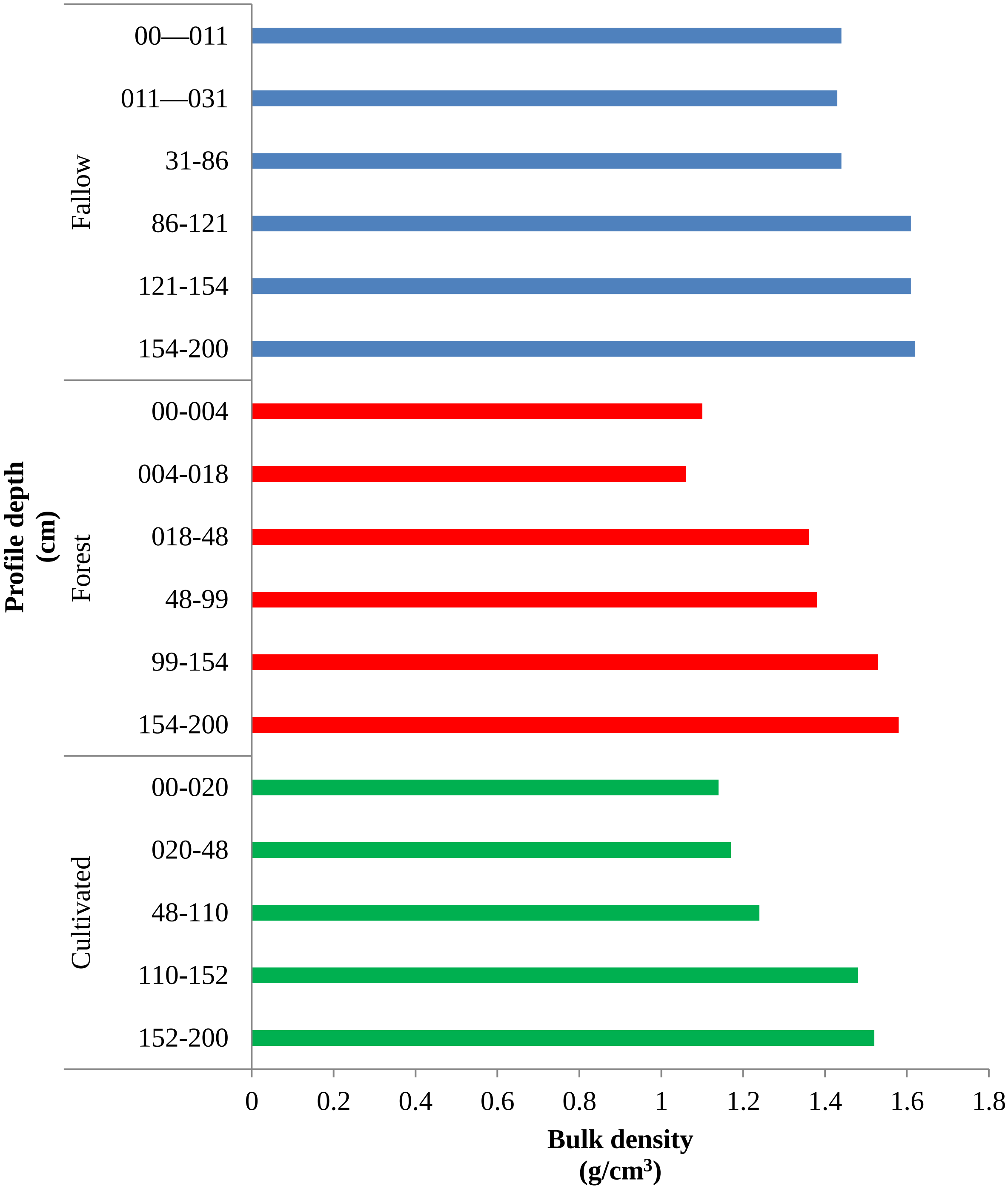


Fig 4.4. Effects of horizon depth (cm) on bulk density (g/cm^3) in soils derived from Coastal plain sand under different land use types.

The mean total porosity of soils formed from the different parent materials ranged between 54 and 60%, with soils derived from Falsebedded sandstone containing higher porosity (Table 4.5). In soils of the different land use types, irrespective of the parent materials, forest soils had higher porosity (65 %, 59 %, 61 %) than other land uses. However, high total porosity observed in soils of the forest land and Falsebedded sandstone could be a reflection of their low bulk density values. Within the profile pits, the values of the soil total porosity decreased down the pits (Appendix 1)

Moisture contents of the studied soils varied significantly for both parent materials-derived soils and land use types ($p < 0.001$). In soils of different parent materials studied, Shale-derived soils had highest percentage moisture content (13%) while those derived from Falsebedded sandstone had the least quantity (9%). However, soils formed from Falsebedded sandstone (9%) and Coastal plain sand (10%) did not vary significantly. High moisture contents in soils formed from Shale may be attributed to high clay content, presence of organic matter and the drainage condition of the soils. Generally, clay has high rate of adsorption and can retain water easily. Moisture content increased with increasing clay content as clay would cause impaired drainage especially at the subsurface horizons (Odunze, 2003). On the other hand, low moisture contents of soils formed from Falsebedded sandstone and Coastal plain sand may be attributed to the texture of the soils. Coarse textured soils are characterized by low moisture content and high drainage, thus resulting to moisture stress.

In soils of the three land use types, forest and fallow lands had higher quantities of moisture when compared with those of the cultivated lands. The low moisture contents of the soils of the cultivated land may be a consequence of poor structural aggregation and removal of vegetative cover. Cultivation deteriorates soil structural aggregation reducing the soil water retention capacity (Wakene, 2001). Furthermore, the removal of the vegetative cover may decrease interception of the atmospheric moisture, increase evaporation and increase soil temperature due to increased solar radiation input to the soil surface. This also encourages surface evaporation thereby stimulating microbial activity and increase rate of organic matter decomposition (Wakene, 2001). Soil moisture had significant positive relationship with organic carbon ($r = 0.650^{***}, 0.544^{***}, 0.634^{***}$). Moisture contents of the soils had significant interaction effects in parent material x land use, land use x pedon ($p < 0.05$), while other interactions did not differ significantly (Table 4.13). These significant interactions revealed variation in moisture retention capacities of soils which may be attributed to parent material, land use systems and other inherent characteristics of soils that encourage good soil water retention (Odunze, 2003).

Soil aggregate stability was measured with both mean weight diameter (MWD) and water stable aggregates (WSA). The average MWD and WSA of soils of the different parent materials ranged between 0.92 and 1.35 mm, 17.11 and 29.23 %, with Shale-derived soils possessing significantly higher ($p < 0.001$) stable aggregates (Table 4.5). In soils under the varying land use types, soils of the forest had significantly higher ($p < 0.001$) stable aggregates (27.37%, 23.17%, 41.40%) compared to those of other land use types (Table 4.6). From the results, both parent material and land use type had profound influence on soil aggregate stability. Comparing the aggregate stability in forest and cultivated land, the results confirm those of Oguike and Mbagwu, (2009); Spaccini *et al.,* (2002) who reported reduction in soil aggregate stability when forest land was converted to cultivated land. Tillage practice together with reduced organic matter content may explain the low value of soil aggregate observed in cultivated land while higher soil organic matter and little or no soil disturbance explained high aggregate stability in forest soils. According to Mill and Fey, (2003), the removal of nutrients can also have effects on soil structural stability, calcium, for example, is an aggregating force in many soils and removal of calcium via cropping could reduce soil structural stability. WSA had significant positive correlation with organic matter ($r = 0.620$, $r = 0.506$, $r = 0.646$) ($p < 0.001$) (Table 4.11). The role of organic materials such as polysaccharides and fungal threads, in binding soil aggregates has been highlighted by numerous authors (Hayness and Swift, (1990), Puget *et al*., (2000), Tisdall and Oades, (1989)). Also, FAO, (2005) reported that organic matter contributes to stability of soil aggregates through the bonding or adhesion properties of organic materials, such as bacterial waste products, organic gels, fungi hyphae and worm secretions and casts. At SOC < 2%, soil aggregates were considered unstable, moderately stable at 2-2.5% and very stable at SOC content > 2.5% (FAO, 2005).

4.3 Chemical Properties of Soils

The pH of soils formed from different parent materials investigated were acidic with mean values ranging between 4.52 and 4.93 (pH H_2O) , 3.68 and 3.69 (pH KCl) (Table 4.7). The acidic nature of the soils studied reveals the inherent characteristics of soils of Southeastern Nigeria irrespective of the parent materials. Foth (2006), Abua *et al*., (2010) and Iwara *et al*., (2011) reported similar findings in some soils of Southeastern Nigeria. In soils of the varying land use types, the mean pH (H_2O) values ranged from 4.28 to 4.64 in soils formed from Falsebedded sandstone, 4.72 – 5.61 in soils of the Coastal plain sand, 4.27 – 5.57 in those derived from Shale (Table 4.8). Soils of the forest had significantly higher ($p < 0.05$, $p < 0.001$) pH values than those of cultivated and fallow lands in soils derived from Falsebedded sandstone and Shale whereas those of the Coastal plain sand did not show significant variation. This finding is in agreement with that of Michel *et al*., (2010) who reported higher pH values in secondary forest than the cultivated soils.

Generally, the pH values obtained in this study across all the land uses and parent materials fall within the range reported by Agbede (2008) and Deekor *et al*., (2012) (4.06 – 5.20) in some soils of South-eastern Nigeria. Concisely, the result clearly showed that soil reaction differed significantly across the parent materials and land use types which could be a consequence of the composition of the parent rocks, land use practices, climate and topography of the areas. Soils of the fallow land were more acidic, owing to more uptakes of basic cations by the plants. According to Offiong *et al*., (2009), differences in quantity and quality of biomass returned to the soil affect soil properties. Furthermore, the results of the soil pH revealed the decreasing quantity of total exchangeable bases with increasing acidity. Soils of the forest land use type with higher pH had higher TEB. In addition to this, soil pH had significant positive relationship ($r = 0.778$, $r = 0.638$,) ($p < 0.001$) with organic carbon (Table 4.11) and did not follow any uniform trend down the profile in all the pedons studied (Appendix 1). Increase in soil pH increases soil biodiversity and mineralization of organic matter with anticipated increase in soil carbon stock due to improved soil water infiltration and aeration (Offiong *et al*., 2009).

Table 4.7:Chemical Properties of Soils derived from different Parent Materials

PM	pH	pH	Avp	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	TEB	Al^{+3}	H^{+}	TEA	ECEC	Al. sat	BS	ESP	Ca/Mg
	(KCl)	(H_2O)	mgkg^{-1}	⟶	⟶	⟶	⟶	cmolkg^{-1}	⟵	⟵	⟵	⟵	⟶	(%)	⟵	
CPS	3.68	4.93	21.42	3.86	2.11	0.11	0.11	6.19	0.91	0.70	1.61	7.91	11.63	78.54	1.81	1.83
FBS	3.69	4.52	17.56	2.76	1.61	0.02	0.05	4.43	0.54	1.49	2.05	6.45	7.83	68.71	1.10	1.71
Shale	3.69	4.73	20.85	4.28	1.49	0.02	0.04	5.83	0.16	0.39	0.55	6.38	3.68	91.42	0.86	2.87
LSD	NS	0.20***	2.42**	0.62**	0.389**	0.02***	0.02***	0.927***	0.151***	0.283***	0.321***	0.939***	2.325***	4.820***	0.538**	NS

PM = Parent material, CPS = Coastal plain sand, FBS = Falsebedded sandstone, ESP= Exchangeable Sodium Percentage, OM=Organic Matter AvP = Available P, TEB = Total Exchangeable bases, AlSat= Aluminum Saturation EA= Exchangeable Acidity BS= Base Saturation, ECEC= Effective Cation Exchange Capacity.

LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant

Table 4.8: Chemical Properties of Soils of the different Land Use Types

Land Uses	pH (KCl)	pH (H_2O)	Av.P ($mgkg^{-1}$)	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	TEB $cmolkg^{-1}$	Al^{+3}	H^{+}	EA	ECEC	Al.sat	ESP (%)	BS	Ca/Mg
							Falsebedded Sandstone									
CL	3.73	4.62	14.91	2.90	1.78	0.02	0.04	4.72	0.28	0.62	0.90	5.66	5.74	0.78	83.58	1.62
Forest	3.64	4.64	19.50	2.98	1.76	0.02	0.10	4.86	0.60	1.81	2.38	7.23	8.45	2.12	65.85	1.69
Fallow	3.73	4.28	18.26	2.36	1.29	0.02	0.02	3.69	0.74	2.04	2.87	6.44	9.29	0.40	56.70	1.83
LSD	NS	0.31*	NS	NS	NS	NS	0.03***	NS	0.11***	0.40**	0.53***	NS	NS	0.81***	10.7***	NS
							Coastal plain sand									
CL	3.69	4.72	22.45	3.69	1.98	0.10	0.12	5.89	0.80	0.37	1.17	7.06	11.50	1.61	83.18	1.86
Forest	3.61	5.16	22.90	4.27	2.12	0.13	0.10	6.63	0.98	0.94	1.73	8.35	11.70	2.13	78.79	2.01
Fallow	3.72	4.90	18.26	3.62	2.22	0.11	0.11	6.06	0.93	0.79	1.93	8.31	11.70	1.71	73.64	1.63
LSD	NS	NS	NS	0.26*	NS	NS	NS	0.33*	NS	NS	NS	NS	NS	NS	5.97*	NS
							Shale									
CL	3.63	4.38	22.92	1.96	0.98	0.02	0.02	2.98	0.31	0.52	0.84	3.77	8.40	0.73	78.80	2.00
Forest	3.72	5.57	17.20	4.56	1.93	0.02	0.08	6.60	0.11	0.52	0.63	7.44	1.86	1.63	86.70	2.36
Fallow	3.70	4.24	20.42	3.33	1.53	0.03	0.01	4.72	0.05	0.14	0.19	5.22	0.81	0.23	90.20	2.18
LSD	NS	0.26***	3.19***	1.66*	0.87*	0.001*	0.04***	2.346*	0.131**	0.34*	NS	2.24*	2.945***	1.19*	8.67*	NS

CL = Cultivated land, ESP= Exchangeable Sodium Percentage, OM=Organic Matter, Av. P = Available P, TEB = Total Exchangeable bases, AlSat= Aluminum Saturation EA= Exchangeable Acidity BS= Base Saturation, ECEC= Effective Cation Exchange Capacity.

LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant.

The mean available phosphorus contents of the soils derived from different parent materials varied from 17.56 - 21.42 $mgkg^{-1}$. The available phosphorus content showed no significant variation with land use types in soils derived from Shale and Coastal plain sand while significant difference was observed in available P contents of soils developed from these two parent materials and Falsebedded Sandstones under the different land uses. In soils of the varying land use types, the average available P content of the soils were rated high as values were higher than the critical levels of 10 – 16 $mgkg^{-1}$ (Adeoye and Agboola, 1985) and 15 $mgkg^{-1}$ (FPDD, 1990) with exception of the cultivated soils derived from Falsebedded sandstone. Contrary to expectation, no significant variation was observed in the available P contents of the soils of the three land use types underlain by Coastal plain sand and Falsebedded sandstone. However, the proportions of available P recorded in all the cultivated soils irrespective of the parent materials were higher than the value of 10 $mgkg^{-1}$ reported by Ekundayo (2004) in cultivated soils of southeastern Nigeria. Higher available P contents of the soils of the cultivated land may be as a result of the addition of the phosphate supplement (agro-chemicals) to enhance soil fertility as reviewed by the land use histories of the studied sites (Table 4.1).

Concisely, high available P obtained across the soils could be a reflection of the organic matter which released phosphorus during mineralization. Organic compounds in soils increase phosphorus availability by the formation of organophosphate complexes that are more easily assimilated by plants, anion replacement of H_2PO_4 from adsorption sites, the coating of Fe/Al oxides by humus to form a protective cover and reduced P fixation (Yihenew and Getachew 2013). The influence of soil organic carbon on phosphorus availability has been reported by Idigbor, *et al*., (2008). Significant positive correlation was recorded between available P and soil organic carbon (r = 0.336***) (Table 4.10). Available P contents of the soils had significant interaction with parent material x land use ($p < 0.05$), while others did not show significant interactions irrespective of the parent materials and land use types (Table 4.14). This significant interaction could be as a result of lithological variation, differences in land use practices, climatic conditions and other soil attributes that favour phosphate mineralization.

Soil total exchangeable bases consist of the base forming cations namely calcium, magnesium, potassium and sodium. The mean calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+}) and sodium (Na^{+}) contents of the soils developed on the varying parent materials studied varied from 2.76 to 4.28 $cmolkg^{-1}$, 1.49 to 2.11 $cmolkg^{-1}$, 0.02 to 0.11 $cmolkg^{-1}$ and 0.04 to 0.11

cmolkg^{-1} respectively (Table 4.7). Falsebedded sandstones-derived soils contained significantly least (($p < 0.01$)) proportion of Ca^{+2} (2.76 cmolkg^{-1}) while those developed on Shale had the highest quantity (4.28 cmolkg^{-1}). High proportion of Ca obtained from soils derived from Shale parent material could be attributed to the composition of the parent material, texture and low leaching capacity of the soils. In most profiles developed on Shale (profiles 10 and 12 for instance), the epipedons (surface horizons) contained higher proportion of calcium ($\geq$ 7 cmolkg^{-1}) compared to the subsurface horizons. Law-Ogbomo and Nwachokor, (2010) reported 5.92 – 7.92 cmolkg^{-1} of calcium while Onweremadu *et al*., (2011) reported calcium content of 6.49 cmolkg^{-1} in some southeastern Nigerian soils derived from Shale. The Mg contents of the soils differed significantly with those developed on Coastal plain sands containing higher quantity (Table 4.7). Similarly, soils developed on Coastal plain sands contained significantly higher quantity of K and Na compared to other soils. According to Loide (2004), fine textured soils contained more Ca and Mg than coarse textured soils and their uptake capacity is higher in these soils. Parent material has a significant influence on soil texture which has an important role in the assessment of soil characteristics. The uptake capacity of soil which is an indicator of soil fertility depends on the texture composition of the soil. As the percentage of clay particles and colloids contained in the soil increase, the content of plant nutrient bound by these particles and colloids increases as well (Loide, 2004),. Thus the soils nutrient binding capacity detects how easily the nutrients not bound by the soil particles can be washed out of the soil.

In soils of the various land use types, the forest soils contained higher quantities of exchangeable Ca, Mg and Na when compared with other soils. In soils formed from Shale and Coastal plain sand, calcium contents showed significant variation with land use types whereas those of the Falsebedded sandstone did not vary significantly (Table 4.8). The proportion of exchangeable Ca^{+2} and Mg^{+2} were generally higher than the critical levels of 2.00 and 1.2 cmolkg^{-1} reported by Adeoye and Agboola, (1984) across the land use types studied with exception of cultivated soils derived from Shale. Similarly, the concentration of exchangeable Mg^{+2} was generally higher (sufficient) than the critical level of 0.5 cmolkg^{-1} soil as suggested by Landon (1991); a concentration less than this value would require an application of magnesium fertilizer accordingly. Magnesium and potassium contents of soils derived from Falsebedded sandstone and Coastal plain sand showed no significant variation with land use types whereas those of Shale vary significantly with land use types. In soils formed from Shale and Coastal plain sand, high proportion of exchangeable bases obtained from forest and fallow soils indicates low intensity of rainfall and less leaching losses which could be attributed to potential influence of vegetative canopy which protects the soil from high rainfall intensity, leaching of base cations and runoff. According to Mills and Fey (2003), a forested landscape is likely to have less leaching owing to the high evaporative demand of trees and the greater canopy interception of rainfall than non forested landscape. The results of the exchangeable bases revealed the significant influence of parent materials and land use types on soil properties.

In addition, sodium concentration was low (< 1.0 cmolkg^{-1}) irrespective of parent materials and land use types. As such, none of the soils can be classified as sodic or alkaline soils. Potassium concentration was generally low (< 0.2 cmolkg^{-1}) across all the parent materials and land use types. Sobulo, (1973) attributed the low potassium concentration in the soils of Southeastern Nigeria to the fact that there is generally a low potassium reserve in acid sands. This could be attributed to the highly mobile nature of exchangeable potassium relative to calcium and magnesium and its consequent massive loss through leaching (Madueke *et al*., 2012). Moreso, low concentration of exchangeable K^+ and Na^+ in the soils could be attributed to the chemical composition of parent rocks from which the soils are developed. Nuga *et al*., 2008 reported potassium and sodium contents of 0.05-0.4 and 0.1-0.03 cmolkg^{-1} in soils derived from the Coastal plain sands; Law-Ogbomo and Nwachokor (2010) reported 0.20 – 0.26 cmolkg^{-1} of potassium in soils derived from Shale in South-eastern Nigeria.

Exchangeable sodium percent (ESP) which identifies the degree to which the exchange complex is saturated with Na was very low ranging from 0.86 - 1.81% in soils developed on the different parent materials; and 0.78 - 2.12% in soils of the Falsebedded sandstone under different land use types, 1.16 – 2.13% in soils of the Coastal plain sand under different land use types, and 0.23 – 1.63% in those derived from Shale under different land use types (Tables 4.7 and4.8). Low ESP obtained from this study across all the parent materials and land use types may be a consequence of low sodium content, rainfall pattern and the acidic conditions of the soils.

Exchangeable aluminum (Al^{+++}) varied between 0.16 cmolkg^{-1} in Shale and 0.91 cmolkg^{-1} in Coastal plain sand whereas aluminum saturation ranged from 3.68 - 11 % across the three parent materials investigated (Table 4.7). This result agrees with the report of Sanchez (1976) who stated that there is less than 1.0 ppm aluminum in the soil solution when aluminum saturation is less than 60 %, but rises sharply when aluminum saturation increases beyond 60 %. As such, due to the low aluminum saturation (< 60%) in the soils, there is little risk of aluminum concentration attaining toxic levels.. Al (aluminum) toxicity is recognized as one of the dominant chemical constraints affecting plant growth in acid soils . Balaji *et al*., (2003) stated that among phytotoxic species, Al^{+++} is the most potent and inhibits root growth and uptake of nutrients, which ultimately reduce crop yield.

The mean calcium magnesium (Ca:Mg) ratios obtained from the soils of the various parent materials studied ranged from 1.92 in Coastal plain sand to 2.87 in Shale. Under the different land uses, Ca/Mg ratios ranged between 1.62 and 1.83 in Falsebedded sandstone, 1.63 and 2.01 in Coastal plain sand, 2.00 and 2.36 in Shale. In soils derived from the varying parent materials, Shale-derived soils had significantly higher ($p < 0.01$) Ca-Mg ratio compared to soils derived from Falsebedded sandstone and Coastal plain sand (Table 4.7). Though not statistically significant, forest soils had high Ca/Mg ratios in soils of the Coastal plain sand and Shale. High Ca-Mg ratio recorded in soils formed from Shale and forest soils may be attributed to the texture and calcium contents of these soils. From the results, it was ascertained that soil with high calcium content had high Ca/Mg ratio. According to Loide (2004), the Ca-Mg ratio of sandy soils is always too narrow as far as plant nutrition is concerned. He further pointed out that on the average, loamy and clay soils contained more Ca-Mg ratio than sandy soils. Generally, the Ca-Mg ratio obtained in this study irrespective of the parent materials and land uses were moderate when compared with 3-5:1 (normal range) reported by Landon (1991). According to the report of (NSW) Agriculture, (2002), some agronomist used 4 to 6 as a bench mark for the ratio of the exchangeable Ca to Mg. They claim that this bench mark must be achieved to ensure healthy soil and therefore optimum agricultural production. Scott and Conyers (1995), reported that the concept of Ca/Mg ratio is dominant force in shaping lime and fertilizer recombination.

The average percentage base saturation of soils developed on different parent materials varied between 68.71 to 91.42 % (Table 4.7). Significantly higher percentage BS was obtained in soils derived from Shale while the least value was obtained in Falsebedded sandstone-derived soils. Lower percentage BS in soils of the Falsebedded sandstone could be a reflection of soil pH and low proportion of total exchangeable bases recorded in these soils. The percentage base saturation of the soils of the different land use types differed significantly ($p < 0.001$, $p < 0.05$) (Table 4.7) indicating the influence of land use on soil properties . Irrespective of the parent materials and land use types, the percentage base saturation of the soils were moderate to high and could be attributed to the total exchangeable bases and organic matter contents of the soils. Soil base saturation had significant positive relationship with organic carbon (r = 0.800***, 0.413**) (Table 4.11).

According to the ratings of Esu (1991), Effective cation exchange capacity (ECEC) of the soils was generally moderate ranging from 6.38 to 7.91 cmolkg^{-1} in soils derived from the different parent materials studied. In soils of the different land use types, forest soils contained the highest values (7.23, 8.35, 7.44 cmolkg^{-1}) of ECEC irrespective of parent materials compared to other soils. ECEC of the soils were dominated mainly by the exchangeable bases and fluctuated irregularly with depth in nearly all the pedons (Appendix 1).

4.4 Carbon forms and Dynamics in Soils

The details of Carbon forms and sequestration are presented in Tables 4.9 and 4.10. The mean total carbon contents of soils ranged from 30.20 to 82.80 gkg^{-1} in soils derived from different parent materials . Soils derived from Shale had the least quantity of total carbon (30.20 gkg^{-1}) while those from Falsebedded sandstone had the highest (82.80 gkg^{-1}). Under the varying land uses, total carbon contents varied significantly ($p < 0.001$, $p < 0.05$). In soils derived from Falsebedded sandstone and Shale, forest soils contained higher proportion of total carbon (109.2 kg^{-1} , 42.40 gkg^{-1}) than other land use types while in Coastal plain sand-derived soils, fallow lands contained significantly higher proportion (93.40 gkg^{-1}) (Table 4.10). Generally, values reported in this study were low compared to those reported by Haung and Schoenau, (1996) but higher than those of Onweremadu, (2007b) in selected soils of southeastern Nigeria. The significant variations in total carbon across all the land uses and parent materials investigated may be attributed to heterogeneity in the characteristics of land use pattern and parent material. Furthermore, higher total carbon contents of the forest and fallow lands may be attributed to the organic carbon contents (38.47, 15.74 gkg^{-1}) of these soils. The relationships between organic carbon and total carbon are presented in Figs. 4.5a-4.5c. Mba and Idike, (2011) had reported the significant effects of land use types on total carbon contents indicating low total carbon in cultivated soils of Southeastern Nigeria.

Table 4.9 : Nitrogen and carbon forms and sequestration in soils derived from different parent materials

Parent material	TN $\longrightarrow$	NO_3^- mgkg^{-1}	$\longleftarrow$ NH_4^+	Nstock gNm^{-2}	TC $\longrightarrow$	OC gkg^{-1}	$\longleftarrow$ Inorg. C	OM	C stock gCm^{-2}
Shale	5.49	0.69	0.45	91.00	30.20	17.59	12.61	30.4	3648.00
CPS	8.24	0.22	0.08	248.00	70.70	14.71	56.00	25.40	3551.00
FBS	7.33	1.22	0.67	102.00	82.80	22.08	60.72	38.1	3229.00
LSD	1.776**	0.337***	0.287***	55.40***	8.96***	2.365**	9.05***	7.54**	NS

CPS = Coastal plain sand, FBS = Falsebedded sand stone, TC = Total carbon, OC = Organic carbon, OM = Organic matter, Inorg. C = Inorganic carbon, TN = total nitrogen,

LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant.

Table 4.10 : Nitrogen and Carbon Forms and Sequestration in Soils of different Land Use Types

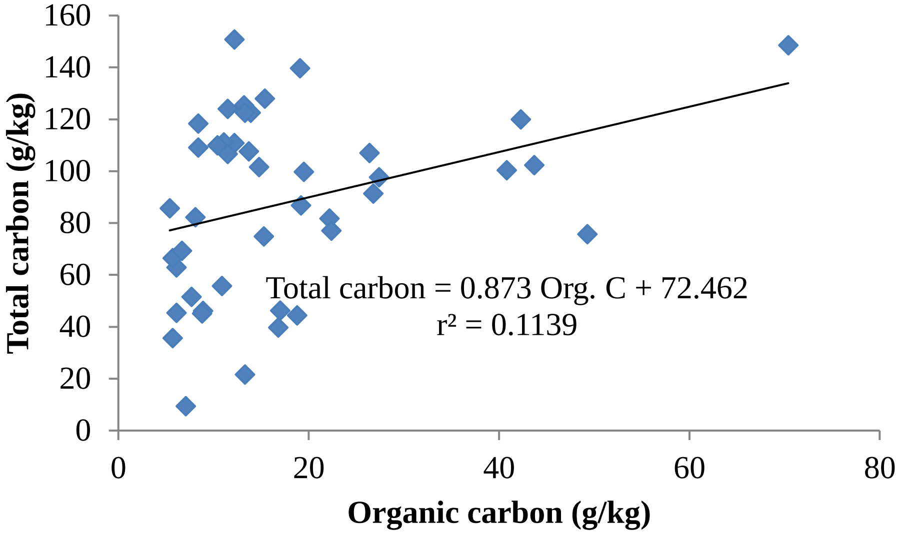
Land uses	TC	OC	OM	Inorg.C	Cstock	TN	NH_4^+	NO_3^-	NStock
	→	gkg^{-1}	←		gCm^{-2}	→	$mgkg^{-1}$	←	gNm^{-2}
				Falsebedded Sandstone					
CL	44.00	12.03	20.7	32.00	2251	3.60	0.26	1.01	66.00
Forest	109.20	38.47	66.30	70.70	2684	14.33	1.35	2.01	105.00
Fallow	95.20	15.74	27.6	79.50	4753	4.06	0.39	0.64	134.00
LSD	16.94***	7.23***	12.47***	17.81***	89.20*	2.48***	0.877**	1.00*	24.55*
				Coastal plain sand					
CL	57.10	8.32	14.30	48.80	2844	7.33	0.04	0.15	330
Forest	61.70	24.60	42.40	36.90	3586	8.56	0.12	0.32	103
Fallow	93.40	11.22	19.30	82.10	4222	8.87	0.07	0.18	313
LSD	21.29*	11.15**	19.23***	21.29***	314*	NS	0.05**	0.24***	136***
				Shale					
CL	26.70	11.22	19.30	15.50	3775	2.01	0.51	0.55	72.60
Forest	42.40	28.64	49.50	13.10	3587	10.49	0.66	0.84	115.10
Fallow	21.60	12.89	22.20	8.70	3583	3.95	0.18	0.68	86.70
LSD	8.93***	5.097***	8.89***	NS	NS	4.356**	0.235**	NS	NS

CL = Cultivated land, TC = Total carbon, OC = Organic carbon, OM = Organic matter, Inorg. C = Inorganic carbon, TN = total nitrogen,
LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant.

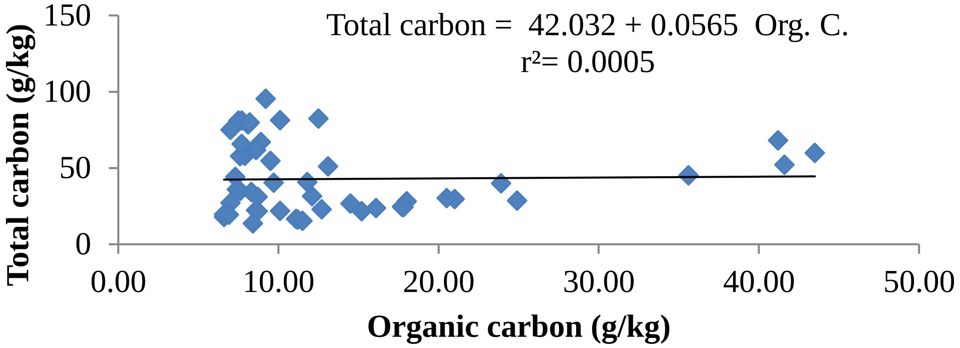
Organic carbon contents of the soils differed significantly across the soils studied. The organic carbon contents of the soils derived from the varying parent materials ranged between 14.71 and 22.08 $\mathrm{gkg^{-1}}$. Soils of the Coastal plain sand had significantly lower ($p < 0.001$) proportion while those of Shale and Falsebedded sandstone had higher values. However, organic carbon constituted about 58% of total carbon in Shale-derived soils, 21% in Coastal plain sand and 28 % in soils formed from Falsebedded sandstone. Thus, the trend of the percentage of organic carbon across the soils of varying parent materials was Shale > Falsebedded sand stone > Coastal plain sand. In addition, the concentration of organic carbon in soils of the Coastal plain sand was rated low while that of Falsebedded sandstone was rated high when compared with the critical level of 2% (20 $\mathrm{gkg^{-1}}$) reported by Chude *et al.*, (2011); Reid and Dirou, (2004). Significantly high quantity of carbon reported in soils of the Falsebedded sandstone and Shale could be explained by the protection of organic carbon by fine particles and considerable low bulk densities of the soils. On the other hand, high bulk density and the coarse nature of soils of the Coastal plain sand may be responsible for lesser proportion of organic carbon in these soils.

In soils of the different land use types, the organic carbon content of the soils varied from 12.03 to 38.47 $\mathrm{gkg^{-1}}$ in Falsebedded sandstone, 8.32 to 24.60 $\mathrm{gkg^{-1}}$ in Coastal plain sand and 11.22 to 28.64 $\mathrm{gkg^{-1}}$ in Shale. From the results, forest soils contained significantly higher proportion of organic carbon than other land use types whereas slight differences were observed in those of fallow and cultivated lands. The differences in organic carbon content of the soils of the three land use types are appreciable and may be linked to the heterogeneity of land use pattern, rainfall and temperature regimes. The low organic carbon content of the cultivated land could be a consequence of agricultural practices, climate and soil conditions that favour rapid decomposition. Conversion of natural forest to cultivated land profoundly modified the microclimate with different vegetation canopy and litter (Senjobi, 2007).

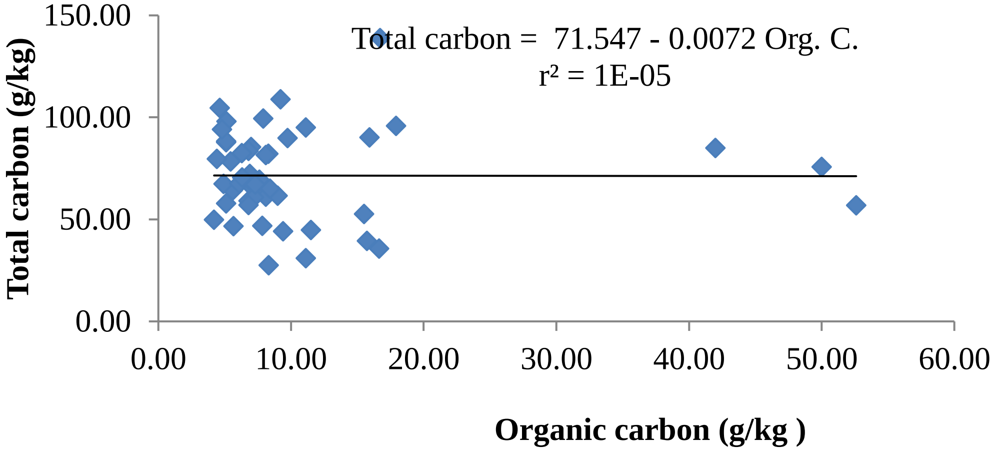
From the results, it was deduced that forest ecosystems appear to be the most conducive-climatic environment for maximum accumulation of organic carbon, thus helping in maintaining soil qualities such as enhanced effective cation exchange capacity (7.23, 8.35, 7.44 cmol/kg), good soil aggregation (27.37, 23.17 and 41.40 %) and reduced soil compaction (0.93, 1.09 and 1.08 $\mathrm{g/cm^3}$) (Tables 4.6 and 4.8).



(a) Falsebedded Sandstone-derive soils



(b) Shale-derived soils



(c) Coastal Plain Sand -derived soils

Figs. (4.5a- 4.5c) : Relationship between total carbon and organic carbon in soils derived from three parent materials

The results of correlation analyses showed that organic carbon corelated significantly with clay (r = 0.513, 0.578) ($p < 0.001$), water stable aggregates (r = 0.506, 0.626, 0.646) ($p < 0.001$) and bulk density (r = - 0.537, - 0.900, - 0.736) ($p < 0.001$) respectively (Table 4.11).
Similar relationship was reported by Jobbagy and Jackson (2000). However, Rice (2002) and FAO (2005), reported that the significant influence of clay on organic matter depends on two mechanisms – first, bonds between the surface of clay particles and organic carbon retard the decomposition process; second, soil with higher clay content increase the potential of soil aggregate formation.

Organic carbon decreased down the profile pits across the soils of the varying land use types (Figs 4.6-4.8). The higher proportion of organic carbon in the epipedons in all the soils of the different land use types is attributable to the fact that most of the organic residues in both cultivated , fallow and forest soils are incorporated or deposited on the soil surface. Top soil organic carbon contents are directly related to organic carbon inputs (Dick and Gregorich, 2004) and there have been a number of studies demonstrating improvements in soil quality and fertility after organic carbon additions (Schjonning *et al*., 1994; Hayness and Naidu, 1998). Similarly, Donahue *et al.* (1990) reported that most arable soils contain 1 – 5 % organic matter, which is mostly within the top 25 cm of the soil, and that this small amount can modify soil physical properties and strongly affect its chemical and biological properties. Another explanation for low organic carbon contents of the subsurface horizons may be absence of roots in the deeper layers (Tables 4.2a – 4.4c). Parent material and land use showed significant interaction in organic matter contents (Table 4.15), indicating influence of land use type on soil organic carbon content.

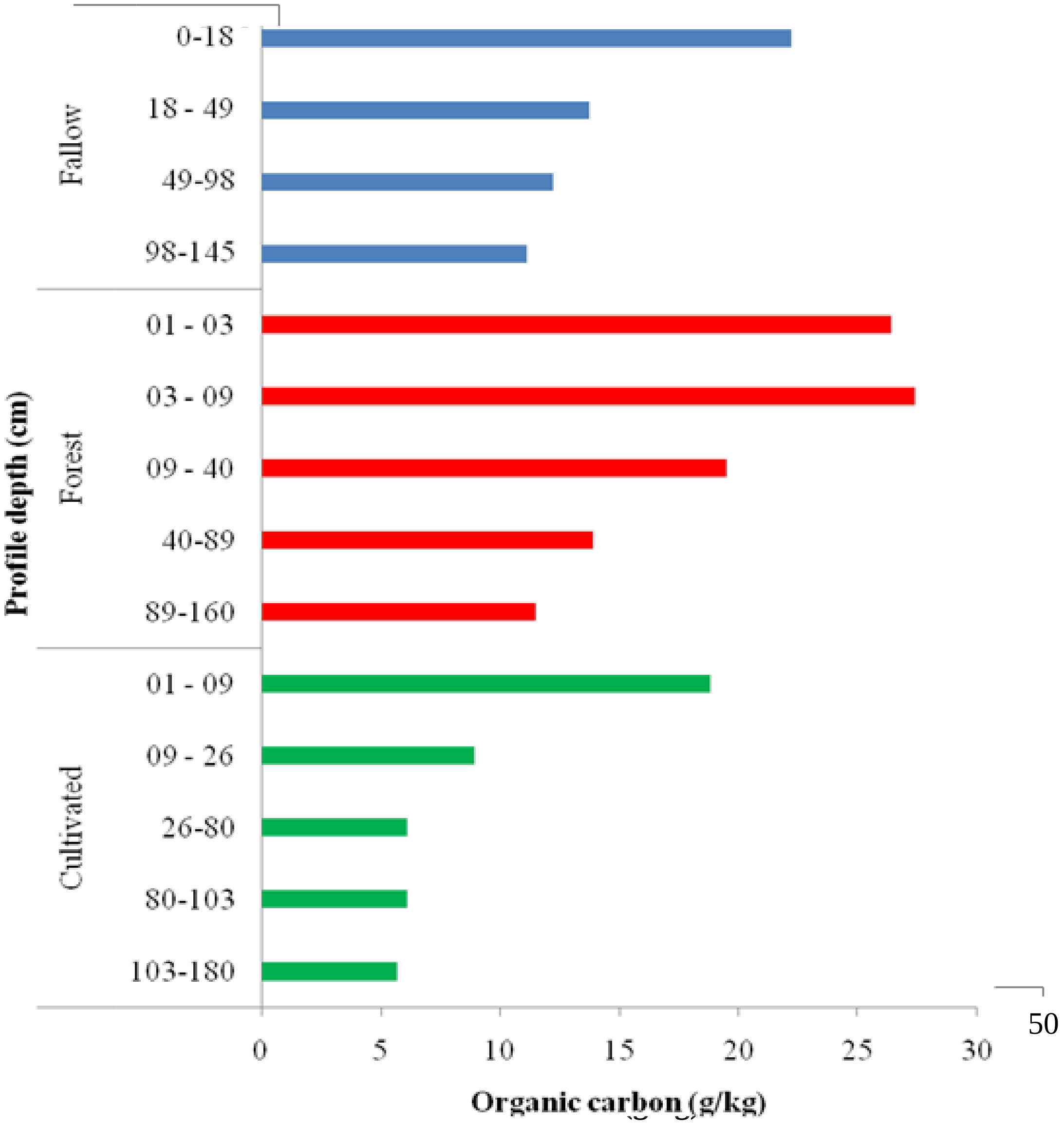


Fig 4.6. Effects of horizon depth (cm) on organic carbon (g/kg) in soils derived from Falsebedded Sandstone under different land use types.

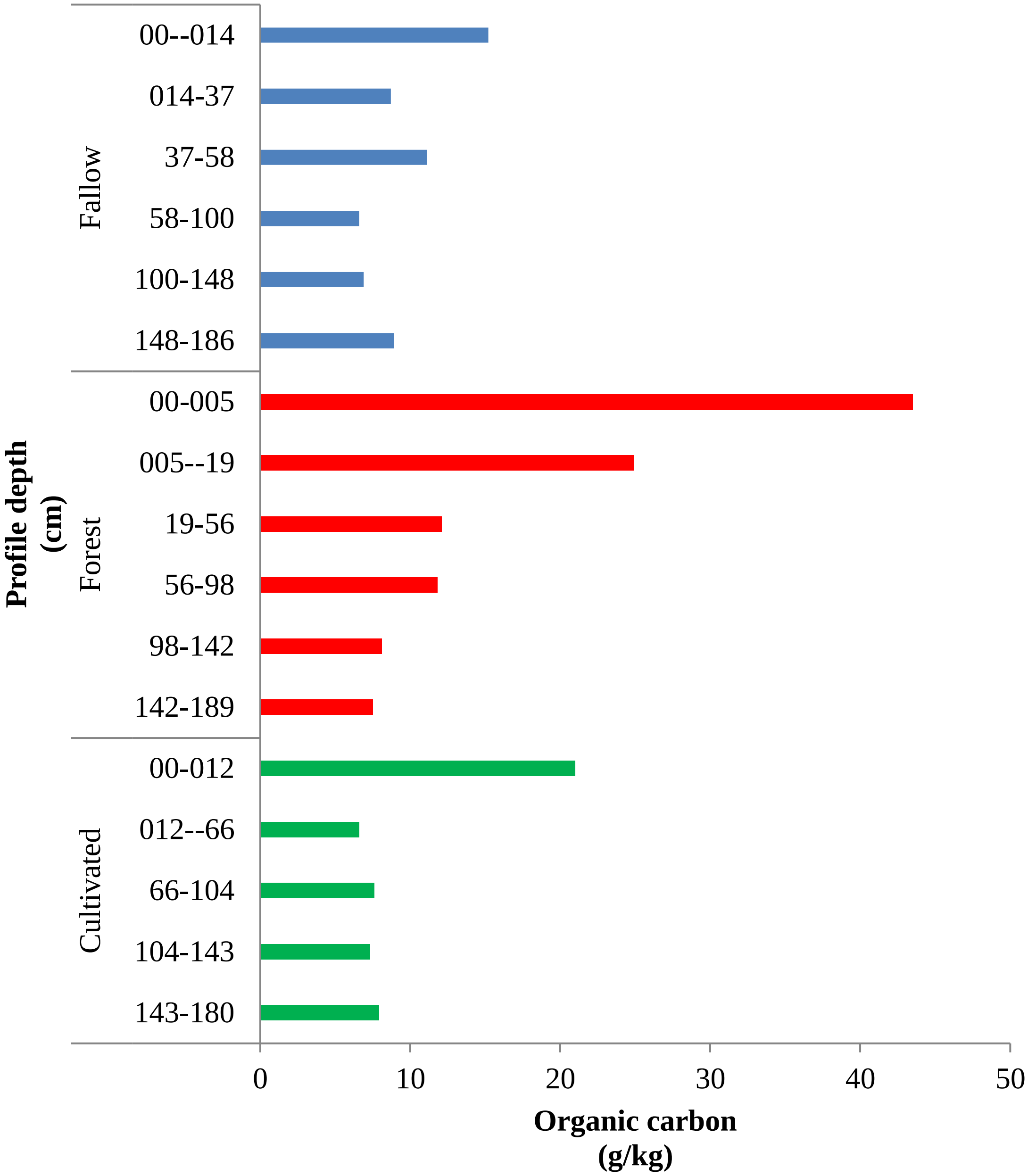


Fig. 4.7. Effects of horizon depth (cm) on organic carbon (g/kg) in soils derived from Shale under different land use types.

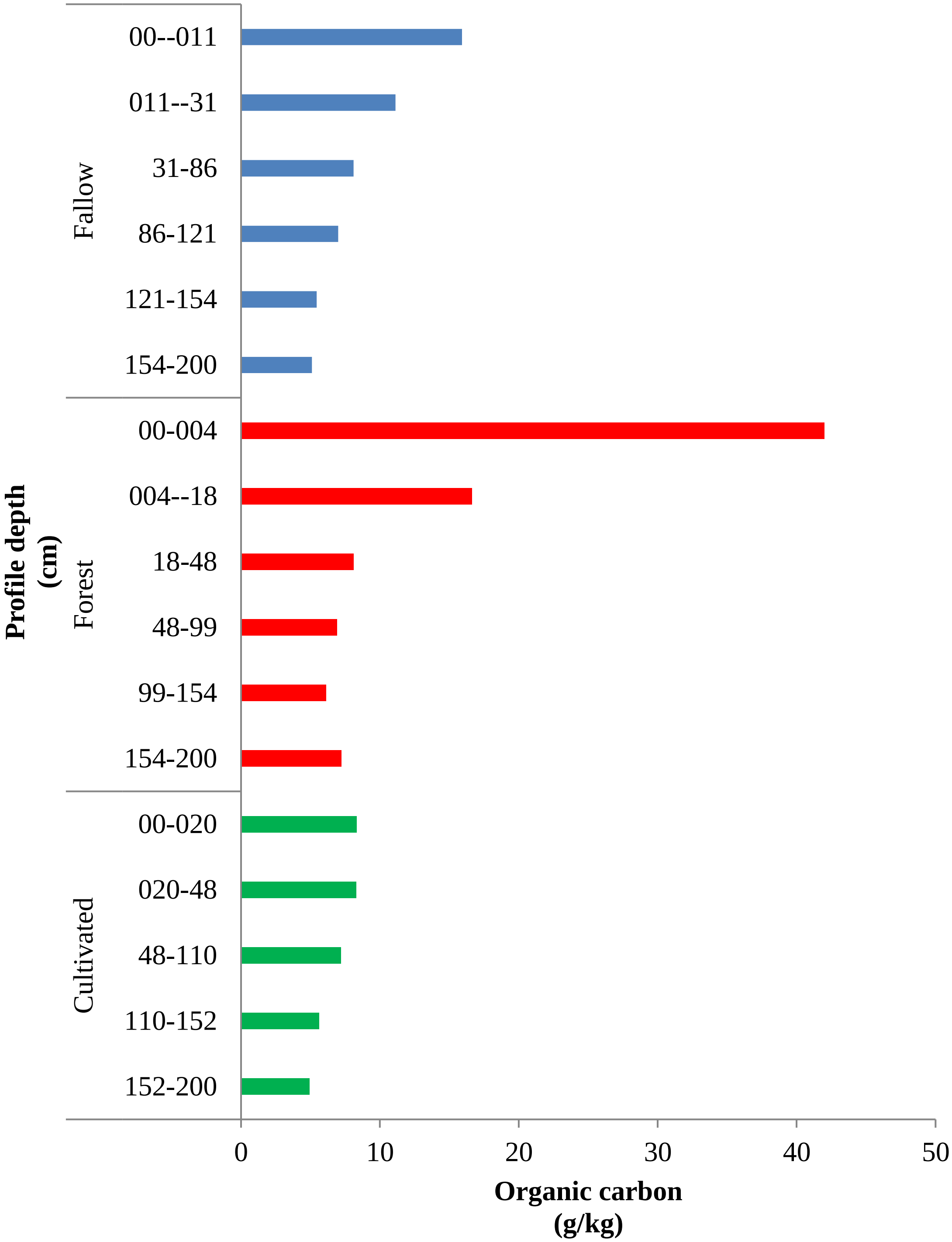


Fig. 4. 8. Effects of horizon depth (cm) on organic carbon (g/kg) in soils derived from Coastal plain sands under different land use types.

Table 4.11: Correlation between Selected Soil Properties and Carbon, Nitrogen Forms and Sequestration of Soils Derived from three different Parent Materials

	TN	NO_3^-	NH_4^+	N Stock	TC	OC	Inorg.C	C Stock	HT
Shale									
Clay	-0.414***	-0.626***	-0.323**	0.451*	0.531***	0.578***	0.720***	0.494**	0.604***
BD	-0.820***	-0.666***	-0.552**	0.194 NS	0.091NS	-0.900***	0.442***	0.495**	0.616***
MC	-0.395***	0.417***	-0.216 NS	0.229 NS	0.316***	0.544***	0.507***	0.370*	0.387**
WSA	0.449***	0.264 NS	0.181 NS	0.019 NS	0.132 NS	0.620***	-0.123 NS	-0.079 NS	-0.357**
pH	0.698**	0.348**	0.581**	0.082 NS	0.101 NS	0.778***	-0.210 NS	-0.160 NS	-0.372**
Avp	-0.133 NS	0.038 NS	-0.217 NS	-0.298 NS	-0.18 NS	-0.248NS	-0.071NS	-0.274NS	-0.079NS
ECEC	0.365***	-0.002 NS	0.188 NS	0.244***	0.387**	0.369***	0.226NS	-0.027 NS	-0.099NS
BS	0.302 NS	0.411***	-0.024 NS	-0.471***	-0.393**	0.413***	-0.528***	-0.385*	-0.424**
Coastal plain sand									
Clay	-0.522***	-0.151 NS	-0.360*	0.478*	-0.10NS	0.512***	0.127NS	0.294 NS	0.707***
BD	-0.332**	-0.280NS	-0.438*	0.519***	0.529***	-0.537***	0.709***	0.865*	0.488***
MC	-0.044NS	-0.660**	-0.275NS	0.384***	0.617***	0.634***	0.659***	0.115NS	0.208NS
WSA	0.200 NS	0.074NS	0.395*	-0.425***	-0.054NS	0.506***	-0.264NS	-0.003NS	-0.357**
pH	0.215 NS	0.004 NS	-0.178 NS	0.143 NS	0.075 NS	0.638**	0.086 NS	0.025 NS	0.009NS
Avp	0.329*	0.719***	0.274 NS	-0.266 NS	-0.254 NS	0.336***	-0.371*	-0.413*	-0.438**
ECEC	0.296 NS	0.105NS	0.210 NS	-0.121 NS	0.097 NS	0.388**	-0.078 NS	-0.017 NS	-0.249 NS
BS	0.178 NS	0.223 NS	-0.096 NS	-0.020 NS	-0.224 NS	0.800***	-0.235 NS	- 0.15 NS	-0.053 NS
Falsebedded sandstone									
Clay	-0.114NS	-0.448**	0.347*	0.551***	0.314***	0.111 NS	0.379***	0.590***	0.413**
BD	-0.721***	0.564***	0.142 NS	-0.552***	0.019 NS	-0.736***	0.322***	0.594***	0.816***
MC	-0.409***	-0.295 NS	0.012 NS	0.330***	0.020 NS	0.650***	0.164 NS	0.366*	0.483**
WSA	0.708***	0.437***	0.274 NS	- 0.071 NS	0.504***	0.646***	0.269 NS	- 0.129 NS	-0.383*
pH	-0.05 NS	- 0.17 NS	0.033 NS	0.09 NS	-0.08 NS	-0.14 NS	-0.035 NS	0.030 NS	0.152 NS
Avp	0.292 NS	0.009 NS	0.169 NS	- 0.10 3NS	0.231 NS	0.133 NS	0.191 NS	-0.07 NS	-0.057 NS
ECEC	0.219NS	0.197 NS	0.072 NS	-0.05 NS	0.309**	0.316 N s	0.199 NS	0.040 NS	-0.167NS
BS	0.049 NS	0.004 NS	-0.19 NS	-0.338 *	0.468**	0.088 NS	-0.532**	-0.314 NS	-0.168 NS

BD = Bulk density, MC = Moisture content, WSA = water stable aggregate, BS= Base Saturation, ECEC= Effective Cation Exchange Capacity, TC = Total carbon, OC = Organic carbon, Inorg. C = Inorganic carbon, TN = total nitrogen, HT = Horizon thickness.

NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$).

Inorganic carbon in soil occurs largely in carbonate minerals such as calcium carbonate ($CaCO_3$) and dolomite ($MgCO_3$) (Schlesinger, 1990; Sombroek *et al*., 1993). The average inorganic carbon contents of the soils across all the parent materials ranged from 12.61 to 60.72 gkg^{-1} (Table 4.9). The highest proportion of inorganic carbon was observed in soils formed from Falsebedded sandstone (60.72 gkg^{-1}) while those formed from Shale had the least quantity (12.61 gkg^{-1}). Low significant quantity of inorganic carbon in Shale could be attributed to low pH and total carbon present in these soils. Batjes (1996) stated that acid and strongly weathered soils do not contain appreciable quantity of inorganic carbon because the carbonates originally present in the parent materials have been dissolved. Across the soils developed on dissimilar parent materials, inorganic carbon constituted about 41.72% in Shale, 79% in Coastal plain sand and 73.3% in Falsebedded sandstone of the total carbon (Table 4.9).

Across the different land use types, inorganic carbon contents varied from 32 – 79.50 gkg^{-1} in soils derived from Falsebedded sandstone, 8.70 – 15.50 gkg^{-1} in those formed from Shale and 36.90 – 82.10 gkg^{-1} in soils derived from Coastal plain sand (Table 4.10). Soils of the fallow land use contained significantly higher ($p < 0.001$) quantity of inorganic carbon in Coastal plain sand and Falsebedded sandstone whereas no significant differences were observed in the three land use types of Shale. Generally, the values of inorganic carbon reported in this study were higher than those reported by Onweremadu, (2007b) in some soils of Southeastern Nigeria. This could be due to variations in chemical reagents and methods used in carbon fractionation. Inorganic carbon correlated positively with total carbon ($r = 918$, $r = 0.905$, $r = 922$) ($p< 0.001$) (Table 4.11) and bulk density ($r = 0.442$, $r = 0.709$, $r = 0.322$) ($p < 0.001$) (Table 4.10). Significant negative correlation was observed between soil inorganic and organic carbon contents ($r = - 0.873^{***}$, $r = - 0.428^{**}$) (Tables 4.12) indicating that increased organic carbon resulted to decreased inorganic carbon. Inorganic carbon contents of the soils had significant interaction effects in parent material x land use ($p < 0.001$) while other interactions were not significant (Table 4.15).

Table 4.12 . Pearson Correlation Matrix among Depth, Carbon and Nitrogen Forms and Sequestration in Soils derived from Different Parent Materials.

	TN	NO_3^- -N	NH_4^+ -N	N Stock	TC	OC	Inorg.C	C Stock	HT
Shale									
TN	1.00								
NO3$^-$ -N	0.615***	1.00							
NH4$^+$ -N	0.512***	0.181 NS	1.00						
N Stock	0.134NS	-0.209 NS	0.079NS	1.00					
TC	0.039NS	-0.326***	-0.02NS	0.443***	1.00				
OC	0.752***	0.603**	0.445*	-0.266 NS	0.023NS	1.00			
Inorg. C	-0.257 NS	-0.540***	-0.198 NS	0.521***	0.918***	-0.873***	1.00		
C Stock	-0.418***	-0.426***	-0.272NS	0.673***	0.197NS	0.651**	0.364***	1.00	
HT	0.534***	-0.520***	-0.308***	0.611***	0.208	0.661***	0.454***	0.874***	1.00
Coastal plain sand									
TN	1.00								
NO3$^-$ -N	0.176 NS	1.00							
NH4$^+$ -N	0.374*	0.133NS	1.00						
N. Stock	0.003 NS	-0.059NS	0.496***	1.00					
TC	0.303 NS	-0.195NS	-0.015NS	0.287NS	1.00				
OC	0.599***	0.081NS	0.685***	-0.477***	0.003NS	1.00			
Inorg. C	0.021 NS	-0.21NS	-0.304***	0.462***	0.905***	-0.428***	1.00		
C Stock	-0.251 NS	-0.143NS	-0.120NS	0.409***	0.095***	0.765**	0.135NS	1.00	
HT	-0.496***	-0.144NS	-0.474**	0.669***	0.016NS	-0.639***	0.287NS	0.704***	1.00
Falsebedded sandstone									
TN	1.00								
NO3$^-$ -N	0.477***	1.00							
NH4$^+$ -N	0.336***	0.162**	1.00						
N. Stock	-0.288 NS	- 0.359**	0.243 NS	1.00					
TC	0.281 NS	- 0.078 NS	0.304**	0.464***	1.00				
OC	0.888***	0.401**	0.232 NS	- 0.265 NS	0.338***	1.00			
Inorg. C	0.666***	- 0.247 NS	0.228 NS	0.601***	0.922***	- 0.052***	1.00		
C Stock	-0.349***	-0.443**	0.399**	0.855***	0.495***	0.649***	0.659***	1.00	
HT	-0.577***	0.560***	0.031 NS	0.734***	0.197 NS	-0.595***	0.452**	0.790***	1.00

TC = Total carbon, OC = Organic carbon, Inorg. C = Inorganic carbon, TN = total nitrogen, HT = Horizon thickness,

NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$).

4.5 Forms and Dynamics of Nitrogen in Soils

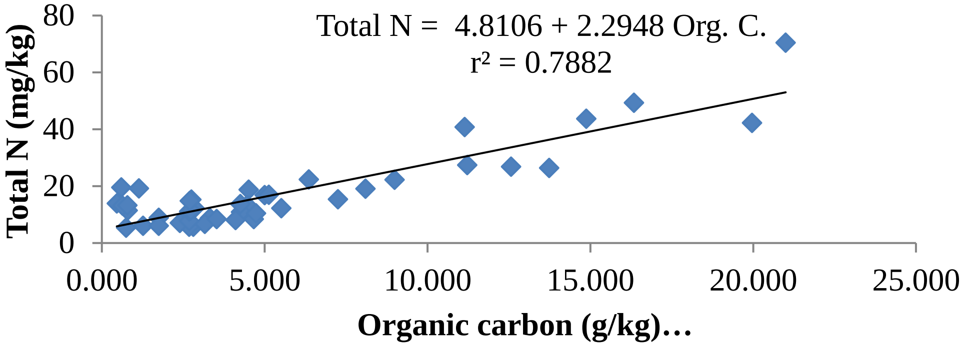
Forms of nitrogen in soils are presented in Tables (4.9 and 4.10). The mean total nitrogen contents of the soils developed on dissimilar parent materials varied between 5.49 and 8.24 mgkg^{-1}. Soils formed from Coastal plain sand and Falsebedded sandstone contained significantly higher ($p < 0.01$) quantity of total nitrogen than those of Shale. In soils of the different land use types, mean total nitrogen contents varied from 3.60 – 14.33 mgkg^{-1} in soils derived from Falsebedded Sandstone, 2.01 -10.49 mgkg^{-1} in Shale-derived soils and 7.33 – 8.87 mgkg^{-1} in soils of the Coastal plain sand . In soils formed from Falsebedded sandstone and Shale, Forest soils contained significantly higher ($p < 0.001$) proportions of total nitrogen (14.33, 10.49 mgkg^{-1}) than fallow (4.06, 3.95 mgkg^{-1}) and cultivated (3.60, 2.01 mgkg^{-1}) soils whereas those of Coastal plain sand were statistically similar. Total nitrogen across the studied soils irrespective of parent materials and land use types were rated low when compared with the critical value of 0.15% (15 mg kg^{-1}) reported by Agboola and Corey, (1975). The low nitrogen concentration is a common phenomenon in the soils of South-eastern Nigeria and is as a result of the high nitrogen losses sustained in these soils through the leaching of nitrates, as well as the rapid mineralization of organic matter under the isohyperthermic soil temperature regime (Eshett, 1987; Eshett *et al.*, 1990). Landon (1991) reported the range of 0.1 – 0.2% (10-20 mg kg^{-1}) of total N to be low in soils of the tropics.

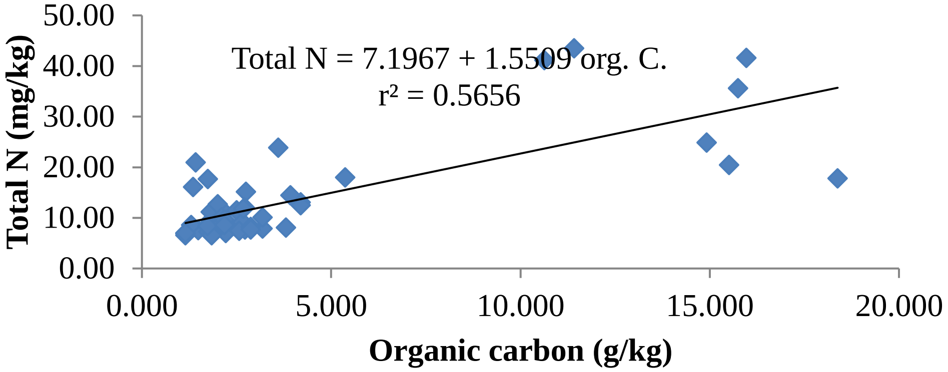
Though not statistically different, fallow lands contained higher proportions of total N than the cultivated lands across the soils of the varying parent materials investigated. Senjobi and Ogunkunle (2011) reported the range of (0.02 -0.16 %) (2 – 16 mg kg^{-1}) total nitrogen in some cultivated soils of Nigeria. Furthermore, low nitrogen contents of the cultivated land may be a result of high exposure of soils to high temperature and low organic carbon contents of the soils. Rates of chemical processes increase exponentially with temperature as long as other factors are not limiting (Meixner and Yang, 2006). The effects of land clearing and tillage practices on soil carbon and nitrogen have been reported by several authors (Senjobi, 2007; Ahukaemere *et al.*, 2012). On the other hand, one possible explanation for high concentration of total nitrogen in forest soils may be due to high plant litter production in these soils which results to high organic matter and total nitrogen concentrations. Parton (1994) suggested that higher nitrogen levels occurred in undisturbed vegetation due to higher number of N-fixing plants. Across the soils studied, surface horizons contained higher quantities of total nitrogen than the sub-surface horizons (Appendix 1). This finding confirms that of Chikezie *et al*., (2007) who reported higher nitrogen level in soil surface than in the deeper horizons in some soils of south-eastern Nigeria. There were strong positive relationships between soil total nitrogen and organic carbon ($r = 0.888$, $r = 0.596$, $r = 0.752$)($p < 0.001$) (Figs 4.9a – 4.9c.), pH ($r = 0.698$) ($p < 0.001$) (Table 4.10). Total nitrogen contents of the soils had significant interaction with parent material x land use ($p < 0.001$) while other interactions were not significant (Table 4.11).

Soil available nitrogen (NO_3^- -N and NH_4^+ - N) differed significantly across the soils and ranged from 0.22 to 1.22 mgkg^{-1} (NO_3^- -N), 0.08 to 0.67 mgkg^{-1} in soils of varying parent materials (Table 4.9). Soils formed from Falsebedded sandstone and Shale had significantly higher ($p < 0.001$) proportions of available N compared to those of Coastal plain sand. These differences could be attributed to texture and organic matter contents of these soils . Sandiness of soils resulting from sandy parent materials reduced retentivity and storage of NO_3^- nitrogen in soils. The trend of the distribution of available N in soils of the different parent materials was Falsebedded sandstone > Shale > Coastal plain sand. However, available N constituted about 26% of total nitrogen in soils developed on Falsebedded sandstone, 21% in those of Shale and 4% in soils derived from the Coastal plain sands indicating that soils of the Falsebedded sandstones contained higher quantity of available nitrogen, followed by those of Shale and lastly by those formed from the Coastal plain sands. Generally, values reported in this study were higher than those reported by Onweremadu, (2007) in some soils of Southeastern Nigeria, and this could be due to variations in chemical reagents and methods used in soil nitrogen fractionation..

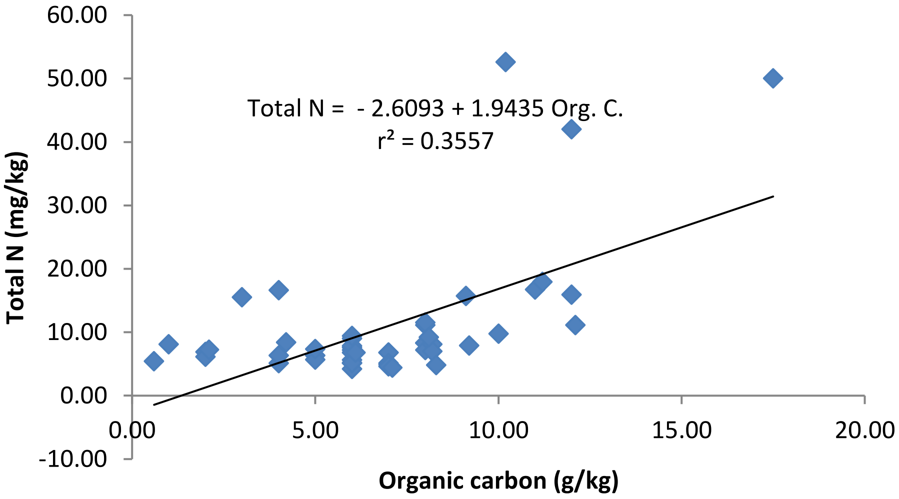
In soils of the different land use types, forest soils accumulated significantly ($p < 0.001$) higher proportion of available N (1.35 mgkg^{-1} (NH_4^+ - N), 2.01 mgkg^{-1} (NO_3^- -N)) in soils of the Falsebedded sandstone, (0.12 mgkg^{-1} (NH_4^+ - N), 0.32 mgkg^{-1} (NO_3^- -N)) in Coastal plain sand, (0.66 mgkg^{-1} (NH_4^+ - N), 0.84 mgkg^{-1} (NO_3^- -N)) in Shale compared to fallow and cultivated soils. This could be attributed to plant (litter) nitrogen content

(Cossey *et al*., 2002), immobilization and mineralization of nitrogen (Uzoho *et al*., 2014; Shi and Norton, 2000) and rate of leaching losses (Hirel *et al*., 2011).



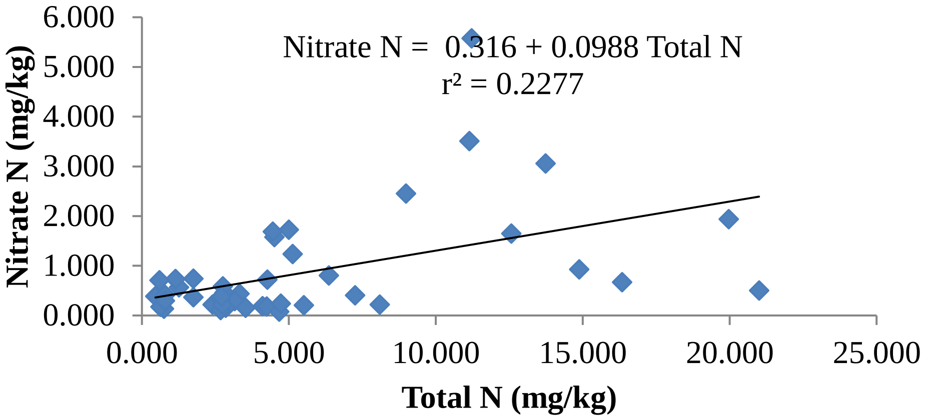


(b) Shale-derived soils

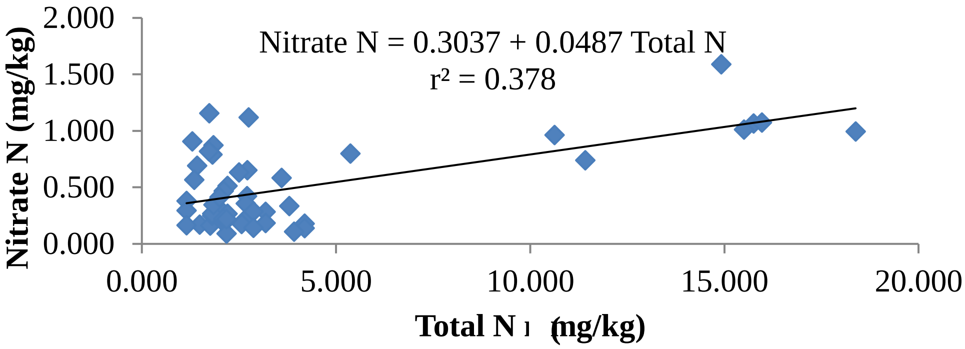


(c) Coastal Plain Sand -derived soils

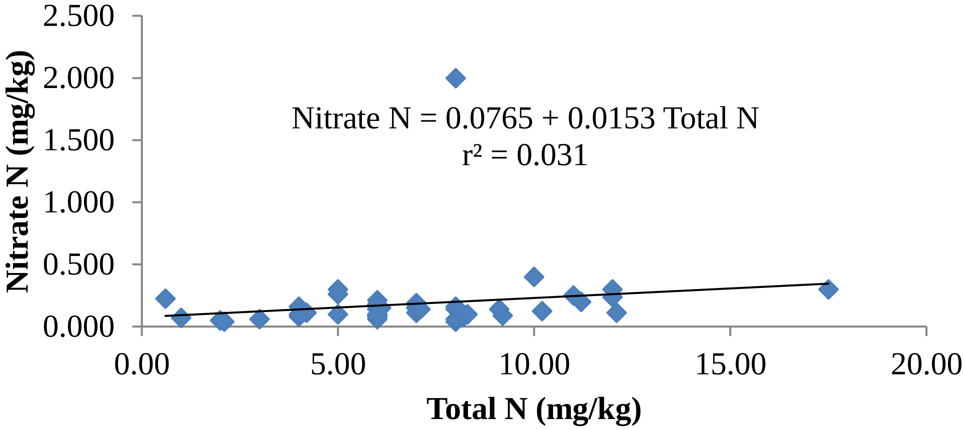
Fig. (4.9a-4.9c) : Relationship between total nitrogen and organic carbon contents of soils derived from the three parent materials.



(a) Falsebedded Sandstone-derived soils

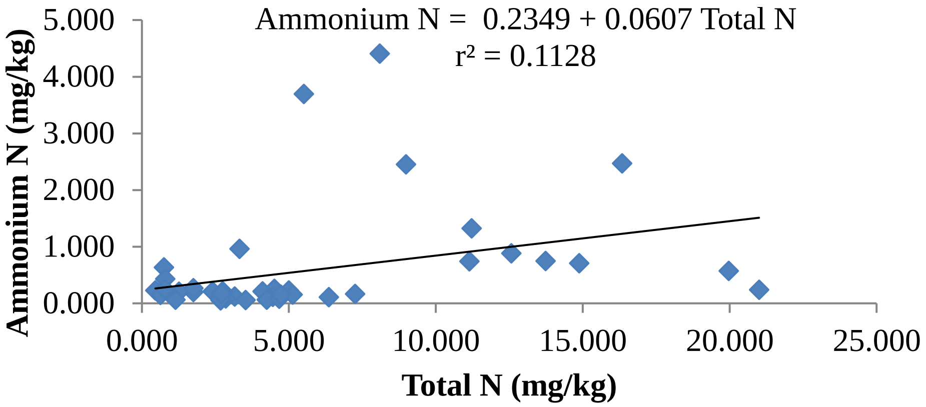


(b) Shale-derived soils

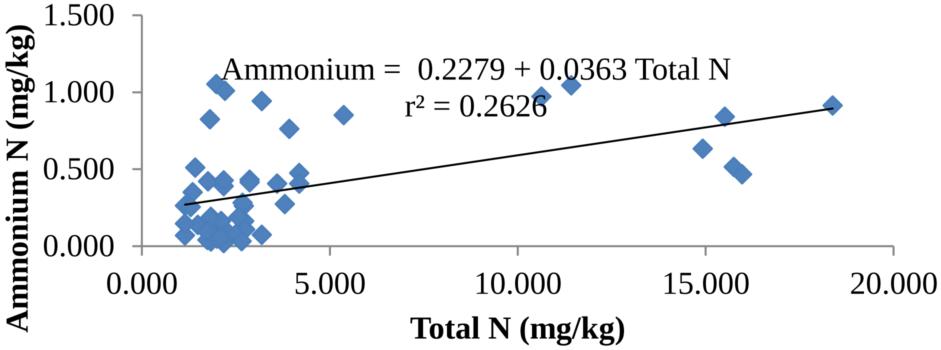


(c) Coastal Plain Sand-derived soils

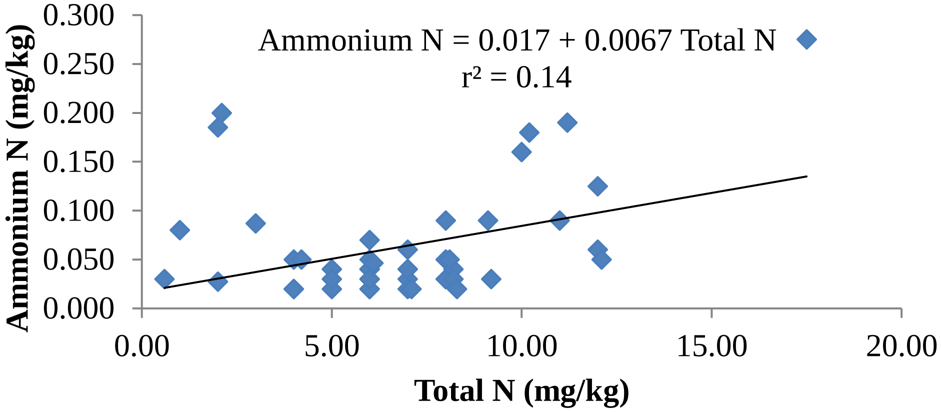
Fig. (4.10a-4.10c) : Relationship between nitrate nitrogen and total nitrogen for the soils formed from three different parent materials



(a) Falsebedded Sandstone-derived soils



(b) Shale-derived soils



(c) Coastal Plain sand-derived soils

Fig. (4.11a-4.11c) : Relationship between ammonium nitrogen and total nitrogen contents of soils derived from the three parent materials

High proportion of available N in soils of the forest is a reflection of their total nitrogen concentration and could be attributed to high litter production by nitrogen fixing plants, mineralization of plant litter, high organic matter content, minimized runoff and less leaching losses. Figs 4.10a – 4..11c showed the relationships between total and available nitrogen contents of the soils. Trees protect the soil from high rainfall intensity and surface runoff. The intense cultivation of soil normally increases the rate of mineralization of the organic carbon (Senjobi 2007; Senjobi and Ogunkunle, 2010), thus negatively affecting the level of N content of the soil. Nitrate-nitrogen had significant interaction with parent material x land use ($p < 0.001$), parent material x pedon while other interactions were not significant (Table 4.13). However, variability in soil nitrogen contents could be attributed to interaction of parent materials, land use and climate within the agro-ecosystem. Results of correlation analyses revealed that NO_3-N had significant ($P < 0.01$) negative correlation with soil moisture ($r = - 0.66$) while significant ($P \leq 0.05$) positive correlation was established between organic matter and nitrate-nitrogen ($r = 0.60$, $r = 0.40$) in soils of the study sites (Tables 4.11, 4.12). Nitrogen is a major organic component in soils next to soil carbon thus justifying its high positive correlation with soil organic matter. The significant negative correlation with soil moisture could be attributed to large pore spaces characteristic of coarse textured soils which is not effective in retaining sufficient water and nutrients (Poach and Faunlkner, 1998). Moving soil water in coarse textured soils leaches soil nutrients including NO_3-N_2 which reaches to surface and ground water where it causes eutrophication. These correlations of NO_3-N_2 are suggestive of the need to use gravimetric soil moisture and soil organic matter in predicting distribution and mobility of NO_3-N in tropical soils for both agronomic and environmental usages.

4.6 Carbon and Nitrogen Sequestration in Soils

Carbon sequestration of soils derived from varying parent materials varied between 3229 and 3648 gCm^{-2} (Table 4.9). Although soils derived from Shale had higher carbon sequestration capacity compared to other soils, no significant variation was discernible among the three parent materials indicating that parent material has little or no influence on the ability of soils to sequester atmospheric carbon. Gray and Murphy

(2002) reported that parent material is a major source of most soil nutrients with notable exception of hydrogen (H^+), nitrogen and carbon, which are primarily derived from the atmosphere and organic material. Nevertheless, high amount of carbon sequestered by soils formed from Shale could be attributed to high clay contents of these soils. Sandy soils have less capacity to stabilize carbon than soils with greater clay content (Powlson *et al*., 2011). In contrast, nitrogen sequestration in soils of different parent materials studied differed significantly ($p < 0.001$) with soils derived from Coastal plain sands having higher quantity (248.00 gNm^{-2}). Least quantity of N was sequestered in soils formed from Shale (91 gNm^{-2}). The higher N storage capacity of soils derived from Coastal plain sand may be attributed to the depth (horizon thickness), bulk density and total N contents of the soils (Tables 4.5, 4.9). N sequestration correlated positively with bulk density ($r = 0.552$, $r = 0.519$) and horizon thickness ($r = 0.699$, $r = 0.669$, $r = 0.734$) ($p < 0.001$) (Table 4.11)

Under different land use types, mean carbon sequestration in soils ranged between 2251 to 4753 gCm^{-2} in Falsebedded sandstone, 2844 to 4222 gCm^{-2} in Coastal plain sand and 3583 – 3775 gCm^{-2} in Shale. The amount of C sequestered in soils under the different land use types varied significantly ($p < 0.05$) in soils formed from Coastal plain sand and Falsebedded sandstone. Fallow soils of these parent materials had the highest quantities (4753 gCm^{-2} , 4222 gCm^{-2}) whereas the least values (2251 gCm^{-2} , 2844 gCm^{-2}) were obtained in soils of the cultivated lands (Table 4.10). In Shale parent material, no significant variation was recorded in soils of the varying land uses. Similarly, there was no significant variation in quantity of nitrogen sequestered in soils developed on Shale under the different land uses. However, cultivated soils sequestered higher quantity of nitrogen (330 gNm^{-2}) than forest soils in Coastal plain sand. In addition to this, in soils derived from Falsebedded sandstone, fallow and forest soils had higher N sequestration values (134 gNm^{-2} , 105 gNm^{-2}) compared with those of the cultivated lands.

The trend of C and N sequestration under the different land use types of Falsebedded sandstone and Coastal plain sand were: fallow > forest land > cultivated land. The higher carbon and nitrogen sequestration capacities of fallow soils may be attributed to the horizons thickness (0-18cm, 18- 49) and bulk density values resulting to greater soil mass. On the other hand, low carbon and nitrogen sequestration in forest soils may be a consequence of thinner horizons (0-5, 5-19cm) and low bulk density observed in all the pedons despite their high organic carbon and TN contents. For instance, the surface horizons of the forest soils were generally thin with thickness varying from 0 – 5 cm with low bulk density ranging between 0.6 and 0.8 g/cm^3 compared to the surface horizons of fallow and cultivated lands with thickness of about 20 cm and bulk density ranging between 1.2 to 1.4 gcm^{-3} . The effects of horizon thickness on carbon sequestration are illustrated in Figs. 4.12-4.14**.** In addition, high C and N sequestration in fallow soils could also be attributed to the age and type of vegetation; and plant's ability to capture and store atmospheric carbon and nitrogen since young plants sequester more carbon and nitrogen than old ones (Johnston *et al*., 2009; Poulton *et al*., 2003). Mba and Idike (2011) reported high carbon sequestration in alley cropping farm than in forest soils.

The results from this study also indicated that fallow periods greater than seven years on degraded tropical soils may not be beneficial to soil carbon restoration. Fisher *et al*., (1994) reported significant increased soil carbon sequestration over the first 3 to 6 years only when native tropical savanna was replaced with productive deep rooting exotic grasses. Apart from bulk density and horizon thickness, several authors reported that the ability of soil to capture and secure carbon is a function of land use and management, texture and farming system (Lal, 2004), irrigation and tillage (Del-grosso *et al*., 2005), tillage techniques (Allmaras *et al*., 2004, Anikwe *et al*., 2003), cropping intensity and vegetation cover (Ortega *et al*., 2002) and nitrogen inputs to soil (Potter *et al*., (1997). In view of this, land use type, and vegetation (fallow) age are among the factors that influenced carbon and nitrogen sequestration in the soils investigated. The carbon sequestration capacity of the soils across the parent materials and land use types was within the range reported by Mba and Idike, (2011) (2435-6429 gCm^2) but higher than 62.48 -127.68 t/ha of Abebayehu (2013) and Eswaran *et al*., (1995).

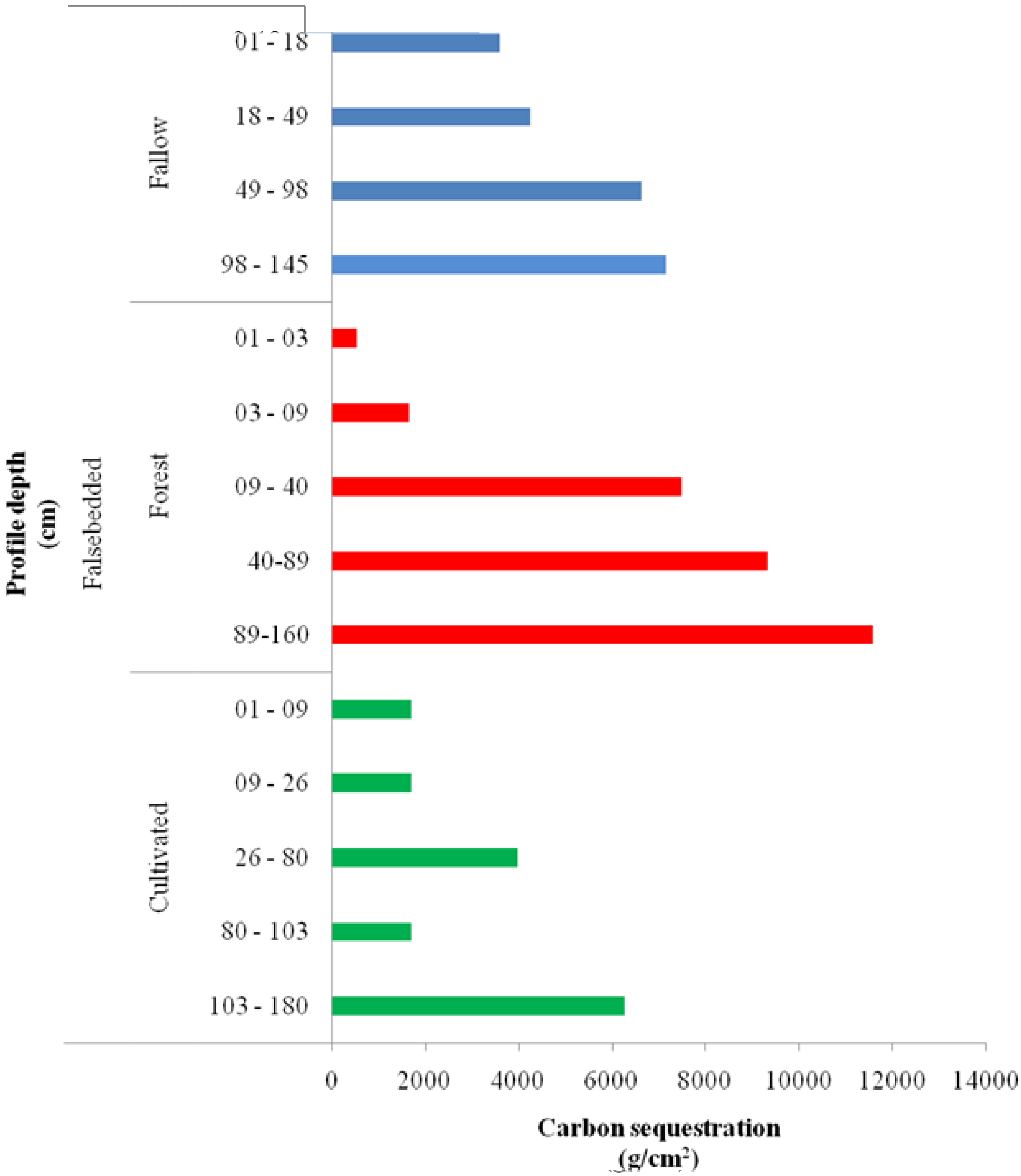


Fig. 4. 12. Effects of horizon depth (cm) on carbon sequestration (gCm^{-2}) in soils derived from Falsebedded Sandstone under different land use types.

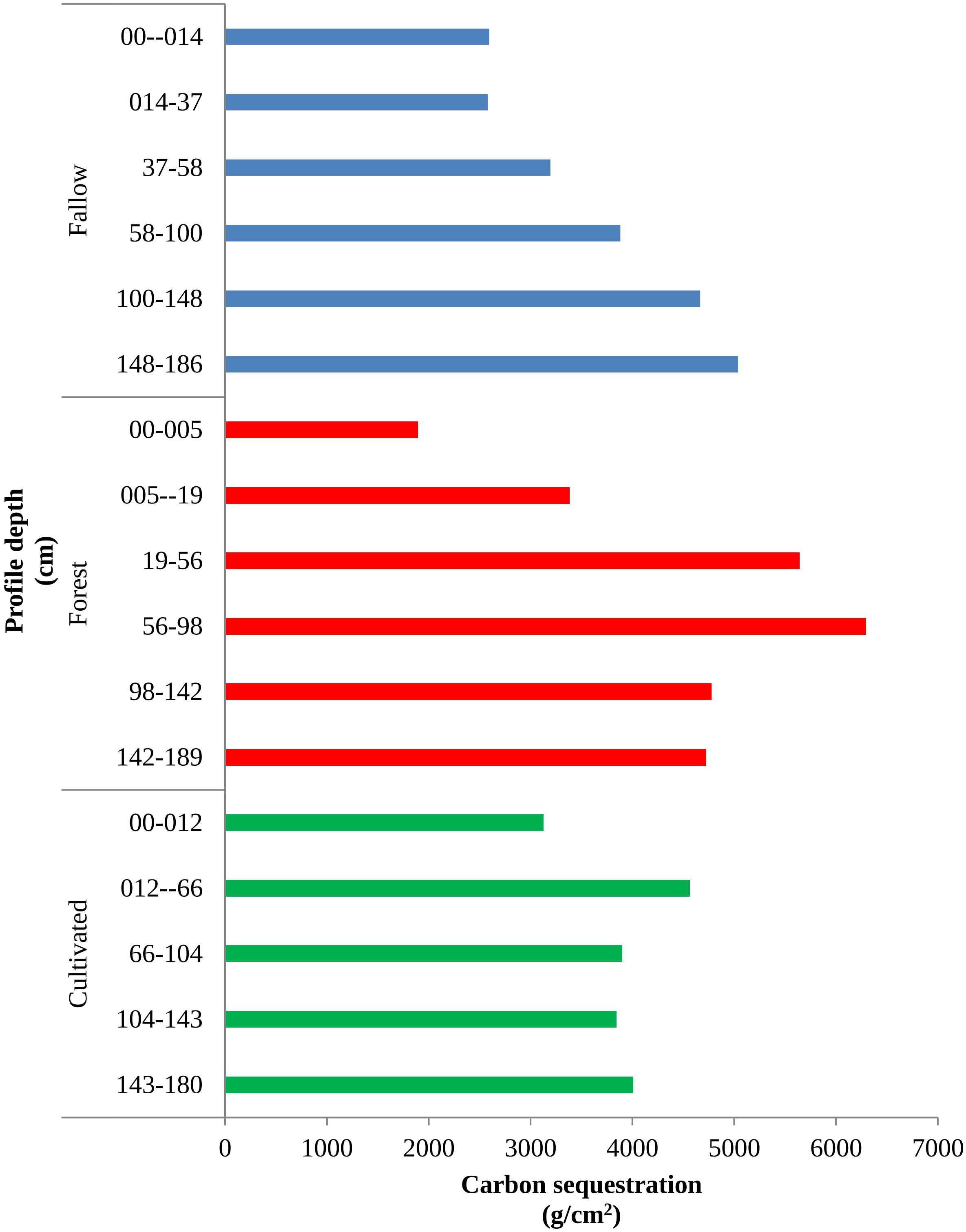


Fig. 4. 13. Effects of horizon depth (cm) on carbon sequestration (gCm^{-2}) in soils derived from Shale under different land use types.

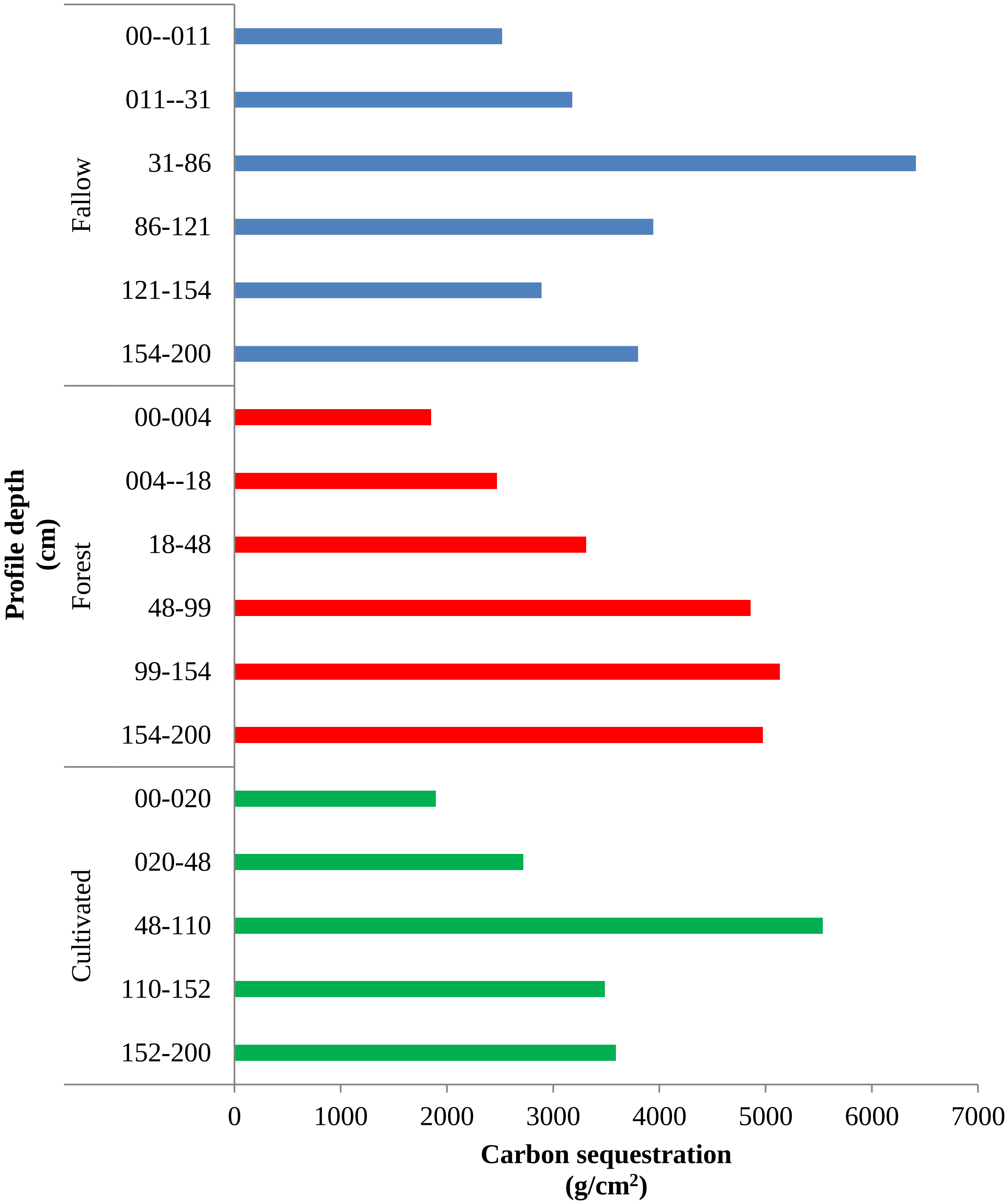
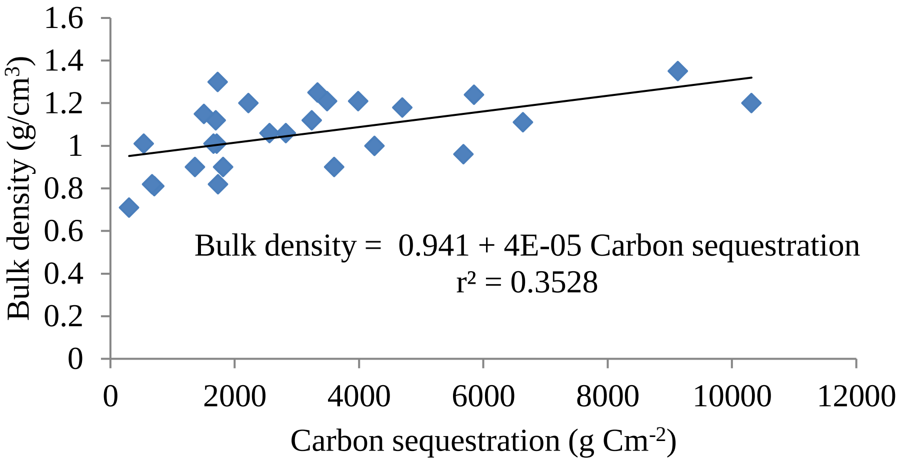
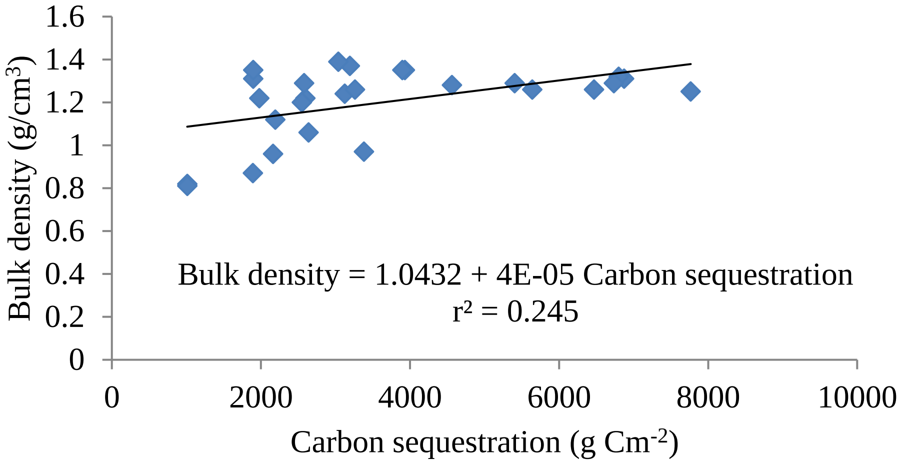


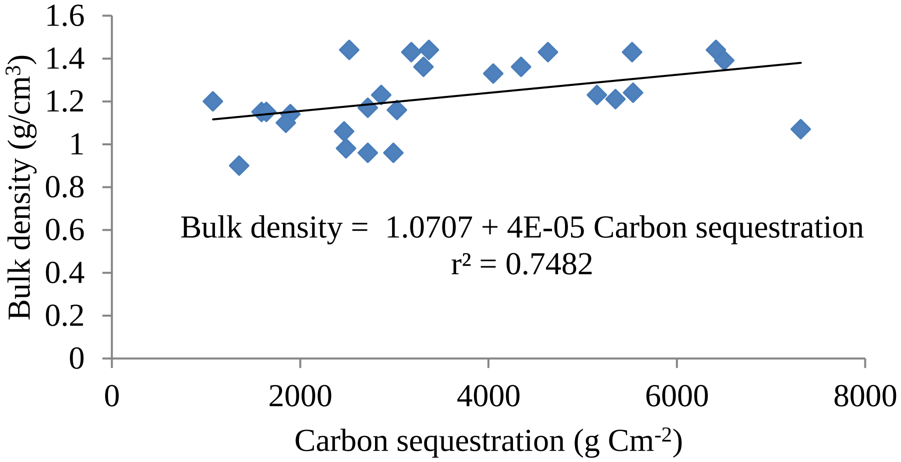
Fig. 4. 14. Effects of horizon depth (cm) on carbon sequestration (gCm^{-2}) in soils derived from Coastal plain sands under different land use types.



(a) Falsebedded Sandstone-derived soils



(b) Shale -derived soils



(c) Coastal Plain Sand-derived soils

Fig. (4.15a-4.15c): Relationship between bulk density values and carbon sequestrations in soils derived from the three parent materials.

From the results, carbon and nitrogen sequestration increased with horizon thickness in all the profiles across the soils (Figs. 4.12 – 4.14). The subsurface horizons contained the highest quantity of stored carbon and nitrogen compared to surface horizons revealing the inherent capacity of these horizons to store more C and N. This finding is consistent with Batjes, (1996), Eswaran *et al.*, (1995), Mba and Idike, (2011) and Abebayehu (2013) who reported high carbon storage in the deeper horizons. According to Mba and Idike (2011), carbon has higher density near the surface but soil organic carbon decomposes rapidly releasing CO_2 to the atmosphere, thus some carbon became stabilized especially in the lower part of the profile. IPCC (1992) also revealed that large amounts of carbon which are not yet considered in most global carbon budgets are stored between depths of 100 cm and 200 cm. They further stated that much of this deeper carbon occurs in more stable forms and therefore will not contribute much to current gaseous emission. In addition, effect of agricultural activities (conversion of forest to arable land) on carbon and nitrogen was largely restricted on the top soil thus causing carbon stored below this depth to be more stable under all vegetation type.

Carbon sequestration correlated positively with horizon thickness ($r = 0.874$, $r = 0.704$, $r = 0.790$) ($p < 0.001$) (Table 4.12), bulk density ($r = 0.495^{**}$, $r = 0.865^{*}$, $r = 0.549^{***}$) (Figs. 4.15a -4.15c**.**) and organic carbon ($r = 0.651$, $r = 0.765$, $r = 0.649$) ($p < 0.001$) (Table 4.12), respectively. These relationships indicate the potential influence of these soil parameters on carbon sequestration. Also, soil moisture contents correlated positively with carbon sequestration ($r = 0.370^{*}$, 0.366^{*}) (Table 4.11). Soil moisture retention influences the level of carbon dioxide fluxes in the soil which may in one way or the other affect soil microbial biomass and potential mineralization of carbon (Haney *et al*., 2004). Also when the moisture content of the soil is in excess, the level of carbon dioxide diffusivity is reduced (Smith *et al*., 2003). Carbon sequestration capacity of the soils had no significant interaction effects in parent material x land use , land use x pedon, parent material x pedon, parent material x land use x pedon. On the other hand, N sequestration had significant interaction effects in parent material x land use ($p < 0.001$) while other interactions were not significant (Table 4.15)

Table 4.13: Interactions among the varying Parent materials, Land use types and Pedons for Selected Soil physical Properties

Soil property	Sources of variation	Df	F-pr	LSD
Sand	Parent material x land use type	4	0.038	12.03*
	Parent material x pedon	4	0.545	NS
	land use type x pedon	4	0.532	NS
	Parent material x land use type x pedon	8	0.959	NS
Clay	Parent material x land use type	4	0.0284	7.689*
	Parent material x pedon	4	0.921	NS
	land use type x pedon	4	0.562	NS
	Parent material x land use type x pedon	8	0.984	NS
Bulk density	Parent material x land use type	4	0.005	0.079**
	Parent material x pedon	4	0.002	0.079**
	land use type x pedon	4	0.101	NS
	Parent material x land use type x pedon	8	0.020	0.136*
WSA	Parent material x land use type	4	0.009	4.168**
	Parent material x pedon	4	0.002	4.168**
	land use type x pedon	4	0.548	NS
	Parent material x land use type x pedon	8	< 0.001	7.219***
MC	Parent material x land use type	4	0.035	2.290*
	Parent material x pedon	4	0.576	NS
	land use type x pedon	4	0.042	2.290*
	Parent material x land use type x pedon	8	0.199	NS

WSA = Water stable aggregates, MC = Moisture content, Df = degree of freedom, LSD = Least significant difference, NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$),*=significant($p<0.05$).

Table 4.14: Interactions among the varying Parent materials, Land use types and Pedons for Selected Soil Chemical Properties

Soil property	Sources of variation	Df	F-pr	LSD
pH	Parent material x land use type	4	< 0.001	0.352***
	Parent material x pedon	4	< 0.001	0.352***
	land use type x pedon	4	0.117	NS
	Parent material x land use type x pedon	8	0.274	NS
Av. P	Parent material x land use type	4	0.003	4.191**
	Parent material x pedon	4	0.927	NS
	land use type x pedon	4	0.866	NS
	Parent material x land use type x pedon	8	0.341	NS
TEB	Parent material x land use type	4	0.023	1.605*
	Parent material x pedon	4	0.286	NS
	land use type x pedon	4	0.901	NS
	Parent material x land use type x pedon	8	0.401	NS
EA	Parent material x land use type	4	< 0.001	0.557***
	Parent material x pedon	4	0.136	NS
	land use type x pedon	4	0.021	0.557***
	Parent material x land use type x pedon	8	0.099	NS
BS	Parent material x land use type	4	< 0.001	8.349***
	Parent material x pedon	4	0.040	8.349*
	land use type x pedon	4	0.082	NS
	Parent material x land use type x pedon	8	0.221	NS

Av.p = Available phosphorus, TEB = Total exchangeable bases, EA = Exchangeable acidity, BS = Base saturation, Df = degree of freedom, LSD = Least significant difference, NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$).

Table 4.15: Interactios among Parent materials, Land use types and Pedons for C and N Forms and Sequestration

Soil property	Sources of variation	Df	F-pr	LSD
TN	Parent material x land use type	4	< 0.001	3.076***
	Parent material x pedon	4	0.612	NS
	land use type x pedon	4	0.611	NS
	Parent material x land use type x pedon	8	0.510	NS
NO_3^-	Parent material x land use type	4	0.008	0.583**
	Parent material x pedon	4	0.026	0.583*
	land use type x pedon	4	0.043	0.583*
	Parent material x land use type x pedon	8	0.138	NS
NH_4^+	Parent material x land use type	4	0.022	0.497*
	Parent material x pedon	4	0.764	NS
	land use type x pedon	4	0.338	NS
	Parent material x land use type x pedon	8	0.042	0.521*
N stock	Parent material x land use type	4	< 0.001	96.00***
	Parent material x pedon	4	0.829	NS
	land use type x pedon	4	0.657	NS
	Parent material x land use type x pedon	8	0.555	NS
TC	Parent material x land use type	4	< 0.001	15.52***
	Parent material x pedon	4	0.386	NS
	land use type x pedon	4	0.361	NS
	Parent material x land use type x pedon	8	0.520	NS
Organic carbon	Parent material x land use type	4	0.025	4.88**
	Parent material x pedon	4	0.896	NS
	land use type x pedon	4	0.810	NS
	Parent material x land use type x pedon	8	0.881	NS
Inorganic carbon	Parent material x land use type	4	< 0.001	15.68***
	Parent material x pedon	4	0.602	NS
	land use type x pedon	4	0.398	NS
	Parent material x land use type x pedon	8	0.674	NS
Carbon stock	Parent material x land use type	4	0.128	NS
	Parent material x pedon	4	0.387	NS
	land use type x pedon	4	0.773	NS
	Parent material x land use type x pedon	8	0.140	NS

TN = Total nitrogen, Df = degree of freedom, LSD = Least significant difference, NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$).

4.7 Multiple Linear Regression Models of Carbon and Nitrogen Forms; and Sequestration against Selected Soil Properties

Tables 4.16, 4.17 and 4.18 show the Multiple linear regression models of carbon and nitrogen forms and sequestration against selected soil properties on the basis of the various parent materials. The multiple linear regression model was used to determine the effects of the soil properties on carbon and nitrogen forms and sequestration in soils. On carbon sequestration versus horizon thickness, bulk density, organic carbon and total carbon, the regression coefficients of determination (R^2) were 0.826 ($p < 0.001$) in Shale-derived soils, 0.693 ($p < 0.001$) in Coastal plain sand –derived soils and 0.744 ($p < 0.001$) in those of the Falsebedded Sandstone respectively. This implies that about 83 %, 69 % and 74 % of variations in carbon sequestration were explained by horizon thickness, bulk density, organic carbon and total carbon respectively. In addition, based on these realities, the selected models were significantly fitted with the existing data meaning that the independent variables namely horizon thickness, bulk density, organic carbon and total carbon had strong relationship with soil carbon sequestration at $p < 0.001$. Similarly, on N sequestration versus horizon thickness, bulk density, nitrate nitrogen and total nitrogen, it was found that the 75 %, 67 % and 57 % of the variation (significant at $p< 0.001$) in soil nitrogen sequestration capacity were due to the aforementioned independent variables in Shale, Coastal plain sand and Falsebedded Sandstone- derived soils. This indicates that these soil parameters had significant influence on nitrogen sequestration and that the selected models were significantly fitted with the existing data. On TN versus clay, bulk density, moisture content and water stable aggregates, the regression coefficient of determination (R^2) was 0.715 ($p < 0.001$) in Shale, 0.552 ($p < 0.05$) in Coastal plain sand and 0.681 ($p < 0.001$) in Falsebedded Sandstone respectively. This implies that about 72 %, 55 % and 68 % of variations in TN were explained by clay, bulk density, moisture content and water stable aggregates. In addition, the model was highly significant ($p < 0.001$) in Shale and Falsebedded sandstone compared to Coastal plain sand that was just significant at ($p < 0.05$). Therefore, based on these realities, the selected models were significantly fitted with the existing data. On TN versus pH, Av.P, ECEC and BS, the models were not significant in Coastal plain sand and Falsebedded sandstone indicating that the aforementioned variables did not have significant influence on TN contents of soils derived from these parent materials. In Shale parent material, the regression coefficient of determination (R^2) was 0.515 ($p < 0.05$) indicating that about 52 % variation in TN was caused by soil pH, available P, effective cation exchange capacity and base saturation. Organic carbon and selected soil physical properties, the results (Tables 4.16 – 4.18) indicate that these full models explained approximately 45 %, 65 % and 86 % variabilities in organic carbon (R^2 = 0.456, 0.649, 0.856)($p < 0.001$). Thus, a significant portion of variability in soil organic carbon is explained by clay, bulk density, moisture and water stable aggregate.

Table 4.16 Multiple Linear Regression Models for Properties of Soils Derived from Coastal Plain Sand

Multiple Linear Regression Model	**R^2**
TN = 13.677 - 0.025 Clay – 5.172 BD + 0.360 MC - 0.032 WSA	0.552*
NO_3^- = 0.732 - 8.427 Clay - 0.495 BD + 0.013 MC + 0.001 WSA	0.083NS
NH_4^+ = 0.169 + 0.00 Clay – 0.66 BD - 0.003 MC + 0.002 WSA	0.528**
Nitrogen stock = -112.519 + 0.94 Clay + 95.68 BD + 24.325 MC - 5.939 WSA	0.642***
Total Carbon = -9.804 - 0.137 Clay + 46.593 BD + 3.830 MC - 0.171 WSA	0.470***
Organic carbon = 34.19 - 0.039 Clay - 22.152 BD + 0.511 MC + 0.396WSA	0.456***
Inorganic carbon = -44.517 – 0.099 Clay + 69.035 BD + 3.335 MC – 0.568WSA	0.592***
Carbon Stock = 401.180 + 6-671 Clay + 2088.226 BD – 79.912 MC + 37.518WSA	0.140 NS
TN = -8.044 + 0.964 pH + 0.179 Av. P + 0.584 ECEC + 0.028 BS	0.208NS
NO_3^- = -0.620 – 0.051 pH + 0.044Av.P + 0.004 ECEC + 0.002 BS	0.525***
NH_4^+ = 0.106 – 0.021 pH + 0.004Av. P + 0.007 ECEC + 0.00 BS	0.163 NS
N Stock = 314.526 + 63.710 pH – 10.476Av. P – 11.834 ECEC – 0.266 BS	0.110 NS
Total C = 97.913 + 62 pH - 1.079 Av. P + 1.609 ECEC – 0.680BS	0.127 NS
Organic carbon = -17.85 – 2.247 pH + 0.656 Av. P + 2.638 ECEC + 0.082BS	0.245NS
Inorganic carbon = 115.35 + 9.946 pH – 1.730 Av. P -1.040ECEC -0.763 BS	0.191 NS
Carbon stock = 5915.75 + 264.410 pH – 129.018 Av. P + 26.976 ECEC – 13.061 BS	0.180 NS
Carbon stock = -832.19 +87.76HT +136.36BD +79.25OC + 4.53TC	0.693***
Nitrogen stock = -544.14 + 7.62HT + 286.15BD + 26.05TN + 35.56NO_3^-	0.670***

NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$)

Table 4.17 Multiple Linear Regression Models for Properties of Soils Derived from Falsebedded Sandstone

Multiple Linear Regression Model	R^2
TN = 13.154 + 0.010 Clay – 12.024 BD – 0.054 MC + 0.352 WSA	0.681***
NO_3^- = 3.01 – 0.01 Clay – 1.726 BD + 0.006 MC + 0.041 WSA	0.670***
NH_4^+ = -0.054 + 0.012 Clay – 0.889 BD + 0.019 MC + 0.02 WSA	0.224NS
N Stock = -660.64 + 2.174 Clay + 456.02 BD + 1.441MC + 6.102 WSA	0.501***
Total C = -48.265 + 0.270 Clay + 45.039 BD – 0.049 MC + 3.411 WSA	0.415***
Organic Carbon = 45.505 + 0.034 Clay – 38.699 BD – 0.210 MC + 0.712 WSA	0.649***
Inorganic Carbon = -93.767 + 0.237 Clay + 83.74 BD – 0.259 MC + 2.699 WSA	0.408***
Carbon Stock = -12838.62 + 50.294 Clay + 9544.066 BD +50.002 MC + 97.436 WSA	0.556***
TN = -0.649 – 1.327 pH + 0.382 Av. P + 0.542 ECEC + 0.034 BS	0.129NS
NO_3^- = 1.891 – 0.440 pH + 0.00 Av. p + 0.140 ECEC + 0.002 BS	0.069NS
NH_4^+ = 0.134 + 0.105 pH + 0.031 Av. P + 0.036 ECEC – 0.012 BS	0.062NS
N Stock = 302.455 + 77.968 pH – 8.167 Av. P 0.585 + ECEC – 5.108 BS	0.167NS
Total C = 106.517 – 0.986 pH + 1.04 Av. P + 7.265 ECEC – 1.170 BS	0.590**
Organic carbon = 12.927 – 5.598pH + 0.398 Av. P + 2.537 ECEC + 0.109 BS	0.142NS
Organic matter = 22.289 – 9.653 pH + 0.686 Av. P + 4.379 ECEC + 0.188 BS	0.142 NS
Inorganic carbon = 93.579 + 4.613 pH + 0.644 Av. P + 4.379 ECEC – 1.279 BS	0.349*
Carbon Stock = 7827.57 + 1015.668 pH – 143.892 Av. P + 229.32 ECEC – 98.876 BS	0.129NS
Carbon Stock = -2622 + 120.65HT +136.78BD + 5.37OC + 38.69TC	0.744***
N Stock = - 97.61 + 6.65HT + 20.35BD + 7.16TN + 5.64 NO_3^-	0.753***

NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$)

Table 4.18: Multiple Linear Regression Models for properties of Soils Derived from Shale

Multiple Linear Regression Model	**R^2**
TN = 35.551 + 0.007 Clay – 28.498 BD + 0.138 MC + 0.027 WSA	0.715***
NO_3^- -N = 2.224 + 0.000 Clay – 1.110 BD + 0.003 MC – 0.002 WSA	0.504***
NH_4^+ -N = 2.091 + 0.000 Clay - 1.463 BD + 0.014 MC – 0.003 WSA	0.330**
N Stock = 74.375 + 0.263 Clay – 72.349 BD + 1.571 MC + 0.752 WSA	0.238NS
Total Carbon = 49.682 + O.119 Clay - 69.459 BD + 1.938 MC + 0.446 WSA	0.477***
Organic carbon = 68.417 + 0.002 Clay – 47.862 BD + 0.038 MC + 0.200 WSA	0.856***
Inorganic carbon = -21.764 + 0.117 Clay – 18..460BD + 1.866 MC + 0.236 WSA	0.560***
Carbon Stock = -4653.769 + 4.229 Clay + 5665.565 BD – 45.819 MC + 33.979 WSA	0.323*
TN = -31.543 + 5.81 pH + 0.207Av. P + 0.201 ECEC + 0.047 BS	0.515*
NO_3^- -N = -1.415+ 0.281 pH + 0.013 Av. P – 0.022 ECEC + 0.006BS	0.282NS
NH_4^+ -N = -1.085+ 0.370 pH + 0.004 Av. P - 0.018 ECEC – 0.003 BS	0.306**
N Stock = 303.788 – 1.104 pH – 3.549 Av. P + 4.616 ECEC – 1.718 BS	0.293NS
Total C = 68.574 1.585 pH – 0.266 Av. P + 3.757 ECEC – 0.454 BS	0.275NS
Organic Carbon = -58.879 + 12.231 pH + 0.097 Av. P + 0.294 ECEC + 0.165 BS	0.697***
Organic matter = -102.029 + 21.135pH + 0.169 Av. P + 0.537 ECEC + 0.286 BS	0.698***
Inorganic carbon = 129.459 – 14.501 pH – 0.352 Av. P + 3.615 ECEC – 0.621 BS	0.373*
Carbon Stock = 15798.350 – 949.828pH – 190.845Av. P – 41.957 ECEC – 36756 BS	0.252NS
N Stock = -286.85 + 2.89HT + 198.87BD +15.45TN – 19.29 NO_3^-	0.745***
Carbon Stock = -8347.02 + 110.67HT + 57.13 BD + 141.95OC – 6.75TC	0.826***

NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$)

4.8 Classification of Soils derived from the different Parent Materials.

Following the characterization and description of the profiles and given their pedogenic and morphological characteristics (Tables 4.2a -4.4a); and their physical and chemical properties (Appendix 1), the soils were classified as follows in accordance with soil criteria outlined in Soil Survey Staff (2003). Taxonomic classification was done to the Subgroup level. The soil classes derived from soil taxonomic classification of the USDA were correlated to the World Reference Base (2006).

Taxonomic classification

Order: At order level, soils were classified as **Ultisols** due to subsurface accumulation of clay, with relatively very strong to strongly acidity (pH 4.1-5.5), low base saturation in most of the argillic horizons and low activity clay reported by Moormann, (1977), Lekwa and Whiteside, (1986) and Federal Department of Agricultural Land Resourses (1990) for soils of southeastern Nigeria.

Suborder: Soils were further classified as **Udults** at suborder level due to the possession of Udic moisture regime reported by FDALR (1985, 1990) for soils in old Imo state.

Great group: At the great group level, profiles 1 – 3, 5, 7- 9 were classified as **Kandiudults** due to the presence of kandic diagnostic features in these profiles.

Profiles 10 – 21 and 24 were classified as **Paleudults** at great group level due to the presence of well developed argillic horizons, 3 % or more clay depletion from the elluvial horizons (Appendix 1) with munsell hue of 7.5 YR or redder, chroma (moist) of 5 or more (Table 4.3-4.4).

At great group level also, Profiles 22, 23, 25-27 were classified as **Hapludults**; while profiles 4 and 6 as **KanHapludults,** because of the possession of no special diagnostic feature at the great group level with irregular clay distribution down the profiles, thus making them a typical of all other great groups under the suborder udults.

Subgroup: At subgroup level, profiles 1, 3 and 5 were classified as **Grossarenic Kandiudults** due to the presence of sandy or sandy skeletal particle size class throughout a layer extending from the mineral soil surface at a depth of 50-200cm (Appendix 1) as well as texture of sandy loam or loamy sand throughout the horizons. Also, Profiles 8 was classified as **Arenic Kandiudults**, profiles 19-21 and 24 as **Arenic Paleudults** due to the presence of sandy particle size class throughout a layer extending from the mineral soil surface to the top of an argillic horizon at a depth of 50-200 cm. (Tables 4.2a - 4.2c, 4.4a – 4.4c).

Profile 23 was classified as **Psammentic Hapludults** because of the presence of sandy particle size class throughout the upper 75cm of the argillic horizon (Table 4.4b).

Profiles 4 and 6 were classified as **Lithic kanhapludults** because of the presence of gravelly or concretionary horizons within 50cm of the mineral surface (Appendix 3).

Profiles 2, 7 and 9 were classified as **Typic Kandiudults,** while profiles 22, 25-27 as **Typic Hapludults** due to the possession of properties typical of the great group kandiudalfs and Hapludalfs respectively.

Profiles 16 - 18 were classified as **Entic Paleudults** due to the presence of a layer of 25cm or more thick that contains less than 27% clay in its fine earth fraction. At subgroup level also, profiles 10-15 were classified as **Vertic Paleudults** because of the presence vertic horizons (horizons that contain 30% clay or more) (Appendix 1), presence of cracks that are about 5mm at the surface horizons and presence of slickensides in a layer of 50cm or more (Appendix 3).

World Reference Base Classification

Profiles 1, 3, 5, 8, 14, 15 19-21 and 24 were classified as **Chromic Acrisols** due to the presence of higher clay contents in the subsoil than in the topsoil leading to argic subsoil horizons, low activity clay with Munsell hue of 7.5 YR or redder, a chroma (moist) of 4 or more (Tables 4.2a - 4.4c,).

Profiles 2, 4, 6, 7, 9 were classified as **Rhodic Acrisols** because they have within depth of 150cm a Munsell hue of 5 YR or redder and a value (moist) less than 3.5 in most of the horizons (Table 4.2a), presence of higher clay contents in the subsoil than in the topsoil leading to argic subsoil horizons. Profiles 22, 23, 25-27 were classified as **Arenic Acrisols** due to the presence of coarse texture (sand, sandy loam and loamy sand) in a layer within 50 -200 cm or more from the surface soil (Tables 4.2a – 4.2c, Tables 4.4a – 4.4c, Appendix 1).

Profiles 10-13, 16-18 as **Haplic Acrisols** due to the presence of of well developed argic subsurface horizons as well as the possession of a typical expression of an Acrisol.

Table 4.19 Classification of soils derived from Falsebedded Sandstone (Ajali formation)

Profile number	Taxonomic classification (USDA)	WRB
Profiles 1, 3, 5	Grossarenic Kandiudults	Chromic Acrisols
Profiles 2, 7, 9,	Typic Kandiudults	Rhodic Acrisols
Profiles 4, 6	Lithic Kanhapludults	Rhodic Acrisols
Profile 8	Arenic Kandiudults	Chromic Acrisols

Table 4.20 Classification of Soils Derived from Shale (Bende Ameki group)

Land use and pedon	Taxonomic classification	WRB
Profiles 10-13	Vertic Paleudults	Haplic Acrisols
Profiles 14,15	Vertic Paleudults	Chromic Acrisols
Profiles 16-18	Entic Paleudults	Haplic Acrisols

Table 4.21 Classification of Soils Derived from Coastal Plain Sand (Benin formation)

Land use and pedon	Taxonomic Class	WRB
Profiles 19-21, 24	Arenic Paleudults	Chromic Acrisols
Profile 22, 25-27	Typic Hapludults	Arenic Acrisols
Profile 23	Psammentic Hapludults	Arenic Acrisols

CHAPTER FIVE

5.1 Summary and Conclusions

The study investigated the sequestration, forms and dynamics of organic components (carbon and nitrogen) of soils of dissimilar parent materials under three different land use types. The study consisted of a 3 x 3 x 3 factorial experiment involving three parent materials, three land use types in each parent material, and three profile pits in each land use type (a total of 27 profile pits) all arranged in a Randomized Complete Block Design (RCBD). Routine (physico-chemical properties) and special (carbon and nitrogen forms and sequestrations) laboratory analyses were carried out on the soil samples. Data obtained from the laboratory analyses were subjected to analysis of variance (ANOVA), multiple regression coefficient and correlation analyses.

Soils derived from Shale had more of blocky structural units and finer particle fractions (clay = 265 gkg^{-1}, silt = 202 gkg^{-1}) compared to those of Coastal plain sands (clay = 90.20 gkg^{-1}, silt = 59.90 gkg^{-1}) and Falsebedded sandstone (clay = 77.3 gkg^{-1}, silt = 141.70 gkg^{-1}). The results of the particle fractions of soils across the varying geology showed that parent material has a significant influence on soil texture which affected the assessment of soil characteristics. The epipedons had structures that are susceptible to erosion compared to the sub-surface horizons. Soils were darker and browner (5 YR 2/4, 5 YR 4/8) on the surface (epipedons) and redder (2.5 YR 6/8, 2.5 YR 7/8, 2.5 YR 4/8) down the profiles irrespective of the parent materials and land use types. However, soils of the forest were darker in all the parent materials studied compared to soils of the fallow and cultivated lands. Soils of the forest land use had higher organic carbon (38.47, 24.6, 28.64 gkg^{-1}), water stable aggregates (27, 23, 41 %) and total exchangeable bases (4.86, 6.63, 6.60 cmol kg^{-1}) compared to other land use types. Higher bulk density values were recorded in soils developed on Coastal plain sand (1.22 gcm^{3}) than those of Shale (1.20 gcm^{3}) and Falsebedded sandstone (1.06 gcm^{3}), forest soils had the least bulk density values (0.9, 1.09, 1.08 gcm^{3}) and higher porosity (65, 59, 61 %) compared to those of fallow and cultivated lands. Shale-derived soils had highest percentage moisture content (13 %) while those derived from Falsebedded sandstone had the least quantity (9.09 %). Forest and fallow lands had higher quantities of moisture when compared with those of the cultivated lands. From the results also, both parent material and land use management had profound influence on soil aggregate stability. Forest soils and soils derived from Shale had significant higher soil aggregates than other soils.

The soils were generally acidic across all the parent materials and land use types with pH values ranging from 3.68 – 3.69 (KCl), 4.52 – 4.93 (H_2O) . Organic carbon decreased down the profile in all the pedons across the soils studied. Soils formed from Coastal plain sand and Falsebedded sandstone contained significantly higher quantity of total nitrogen (8.24 $mgkg^{-1}$, 7.33 $mgkg^{-1}$) than those of Shale (5.49 $mgkg^{-1}$). In soils of the different land use types, forest soils contained higher proportion of total nitrogen, exchangeable Ca^{++}, Mg^{++} and Na^{+} than fallow and cultivated soils. Generally, all the soils studied contained low proportions of K^{+}, Na^{+}, Al^{+++}, aluminum saturation and exchangeable sodium percentage (ESP). Soils formed from Falsebedded sandstone and Shale had significantly higher proportions of available N (1.22 $mgkg^{-1}$, 0.69 $mgkg^{-1}$ (NO_3^{-}), 0.67 $mgkg^{-1}$, 0.45 $mgkg^{-1}$ (NH_4^{+}) compared to those of Coastal plain sand (0.22 $mgkg^{-1}$ (NO_3^{-}), 0.08 $mgkg^{-1}$ (NH_4^{+}). The trend of the distribution of available N in soils of the different parent materials was Falsebedded sandstone > Shale > Coastal plain sand. Available N constituted about 25.78% in soils developed on Falsebedded sandstone, 20.69% in Shale and 3.64% in Coastal plain sand. Forest soils had higher proportion of available N compared to fallow and cultivated soils. Carbon sequestration in soils of the three different parent materials did not differ significantly. In Falsebedded sandstone and Coastal plain sand-derived soils, Fallow land use type had higher carbon sequestration capacity (4753, 4222, gCm^{2} ,) than other land use types studied.The trends of C sequestration in the soils of the different land use types was: fallow > forest > cultivated land in soils developed on Falsebedded sandstone and Coastal plain sand. Generally, carbon and nitrogen sequestration increased with increased horizon thickness.

The soils of the three parent materials were classified as follows : Grossarenic Kandiudalfs (USDA) – Chromic Lixisols (WRB), Typic Kandiudalfs (USDA) – Arenic Lixisols (WRB), Lithic Kanhapludalfs (USDA) – Rhodic Lixisols (WRB), Arenic Kandiudalfs (USDA) – Chromic Lixisols (WRB), Vertic Paleudults (USDA) – Haplic Acrisols (WRB), Psammentic Hapludalfs (USDA)- Arenic Lixisols, Entic Paleudults (USDA) – Haplic Acrisols (WRB)

In conclusion parent materials and land use types had significant influence on soil properties, carbon and nitrogen dynamics and sequestration. Continuous cultivation of land had significant influence on soil organic matter, aggregate stability, bulk density , exchangeable bases, nitrogen and carbon dynamics and ability of soil to sequester carbon and nitrogen. The decline of these vital soil qualities may be attributed to intensive cultivation of soils employed by farmers. Another factor contributing to this change is lack of proper information on soil fertility management by a majority of land users. In addition to land use type and parent material, horizon thickness and age of the ecosystem are crucial factors that influence carbon sequestration. The results further indicated that fallow periods greater than seven years on degraded tropical soils may not be beneficial to soil carbon restoration.

5.1 Recommendations

1. Land use and management practices such as bush fallow and maintenance of forest which help to maintain levels of soil organic carbon and soil fertility, and provides an opportunity to sequester carbon should be embraced. These practices should be up-scaled to cover wider area to promote sustainability of soil. The adoption of the bush fallow method should have some successes in controlling the trend of degradation and decline in soil organic carbon. This practice represents opportunities to accumulate soil organic carbon through the process of carbon sequestration.
2. Continuous cultivation of land and wood harvesting should be discouraged, as these do not only destroy the natural habitat causing an imbalance in the ecosystem but they also cause global warming and exposes the soil to agents of degradation.
3. Since depth (horizon thickness) and age of vegetation were observed in this study to be crucial factors affecting carbon and nitrogen sequestration in soil, further investigations on the effects of these important parameters and other protecting mechanisms favouring carbon and nitrogen sequestration should be the topic of future studies.

References

Abebayehu, A. (2013). Evaluating organic carbon storage capacity of forest soil: case study in Kafa zone Bita District Southwest Ethiopia. American- Eurasian Journal of Agric. and Environmental Science. 13(1) 95-100.

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

Adeoye, G.O., and Agboola, A.A. (1985). Critical Levels for Soil PH, Available P, K, Zn and Mn and Maize Ear – Leaf Content of P, Cu and Mn in Sedimentary Soils of Southwester Nigeria. Fertilizer Research, 6,65 – 75

Agbede , O.O. (2008). Soil Husbandry: Life for National Food Security and Economic Empowerment. An Inaugural Lecture Delivered on 19th, 2008 at Nasarawa State University Keffi, Nigeria.

Agboola, A.A. and Corey, R.B. (1973). The relationship between soil pH, organic matter, available P, exchangeable K and nine elements in the maize tissue. Soil Sci. 115:367-375

Agboola, A.A. (1979). An Agricultural Atlas of Nigeria.Oxford University Press Great Britain.

Agboola, A.A., (1994). A recipe for continuous arable crop production in the forest zone of Western Nigeria, In : Alternative to slash-and burn agriculture; Proceedings of 15th International Soil Science Congress, Acapulco, Mexico, Sanchez, P.A and Van Houten, H., Eds. International Center for Research in Agro-forestry and International Society of Soil Science, Nairobi, 106

Agriculture and Agric-Food Canada, Research Branch (1998), *The Health of Our Air: toward* sustainable agriculture in Canada, 1998.

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

Akamigbo, F.O.R and Asadu, C.L.A. (1983). Influence of parent materials on the soils of Southeastern Nigeria. East Africa Agric. For. J., 48: 81-90.

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

Akamigbo, F.O.R. (1999b). Land capability classification, a tool for effective land use policy. In: FMANR (eds). Proceedings of the national seminar on land use policy for Nigeria held at Ibadan.

Akamigbo, F.O.R., (2001). Soil survey, classification and land use of wetland soils in Nigeria.

Lead paper presented at the 27th Annual Conference of Soil Science Society of Nigeria at the University of Calabar. 5-9 November.

Akamigbo,F.O.R (2010a). The role of soil science in combating environmental and climate change hazards. A solicited paper delivered at HRH Eze Egesie complex, Michael okpara university of agric. Umudike, Umuahia Abia State, Nigeria. 22pp.

Akamigbo,F.O.R (2010b). Soil: Fundermental methods of soil resource survey, classification, interpretation and application. Published and printed by University of Nigeria Press Ltd. University of Nigeria, Nsukka Pp 176

Akankpo, A.O and Igbokwe M.U (2012). Preliminary lithologic deductions for Michael Okpara University of Agriculture Umudike, Abia State Nigeria using vertical electrical sounding method. Archives of Physics Research, 3(4): 292-302.

Aletta, A., Davis, M.H.S., and Jana, E.C. (2004). Spatial distribution of soil carbon in southern new England hardwood forest landscapes. Soil Sci. Soc. Am. J. 68:895-903

Allmaras, R.R, Linden D.R, and Clapp, C.E. (2004). Com-residue transformation into root and soil carbon as related to nitrogen, tillage, and stover management. Soil Sci. Soc. Am. Journal 66:1366 – 1375.

Aluko, A.P. and Fagbenro, J.A. (2000). The role of tree species and land use system in organic matter and nutrient availability in degraded ultisols of Onne, Southeastern Nigeria. Proc. Of Annual Conference of Soil Science Society of Nigeria, Ibadan, Oyo state. Pp 89-292.

Alvarez, R and Alvarez, C.R., (2000). Soil organic matter pools and their associations with carbon mineralization kinetics. Soil Science Society of American Journal 64(1): 184-189. and Water Conservation (WASWC). Special publication No. 2. Beijiing, China.

Angers, D.A and Erikson-Hamel, N.S. (2008). Full inversion tillage and organic carbon distribution in soil profiles: a meta-analysis. Soil Science Society of America Journal. 72, 1370-1374.

Anikwe, M.A.N., Obi, M.E., and Agbim, N.N (2003). Effect of soil and crop management practices on soil compactibility in maize and groundnut. Plant and Soils. 253: 457-465.

Anikwe, M.A.N. (2010). Carbon storage in soils of Sout-eastern Nigeria under different management practices. Carbon balance and management. 5(5) 1-7.

Ann-Katrine, H.C., (2011), Carbon storage and turnover. Soil Research:11, 25

Anonymous (2005). Land use policy and sustainable diminitiative in Nigeria in managing the soil resources for food security and environment. Proceedings of 29th Annual Conference of Soil Science Society of Nigeria. Pp 57-62.

Anonymous (2006). Soil structure and what it tells us. Soil training. Pp 18.

Arbestain, M.C., Pardo-Lorenzo, R. Gonzalez-Arias, A. Virgel, S. Anza M. and Macias, F. (2007). Effect of parent material and pedogenic processes on the distribution, forms and dynamic of organic carbon in forest ecosystem in NW Spain. A biochemical approach. In: Ecology Research Progress ed. S.I. Munoz. Pp 117-153.

Aruleba, J.O. (2004). Influence of cropping systems and land use types on land suitability and degradation in southeastern Nigeria. A Ph.D thesis in the Department of agronomy, University of Ibadan. P 242.

Asadu, C.I.A, Ezeaku, P.I. and Nnaji, G.U. (2004). Land use and soil management situations in Nigeria: An Analytical review of changes. Outbreak on Agriculture 33: 27 – 37 UK.

Atlas of Imo State Geology, (1984). Geology Map of Old Imo State.

Attah, L.E. (2001). Physico-chemical characteristics of the rhizosphere soils of some cereal crops in Ambo Woreda, West Shoa, Ethiopia. Maejo International Journal of Science and Technology 4(10) 93-100

Australian Greenhouse office (2000). Greenhouse sinks and the Kyoto protocol – An issues paper. Australian Greenhouse office, common wealth of Australia.

Awotoye O.O., Ogunkunle, C.O. and Adeniyi S.A. (2011). Asssessment of soil quality under various land use practices in a humid agro-ecological zone of Nigeria. African Journal of Plant Science . 5(10). 565-569

Awdenegest, M., Melku D; and Fantawy. (2013). Land Use effects on soil quality indicators: A case study of Abo-Wonsho southern Ethiopia, Journal of applied and & Environmental soil science. Volume 2013 PP9.

Ayodele, O.J. (1986). Effect of continuous maize cropping on yield, organic carbon mineralization and phosphorus supply of soils in Western Nigeria. Bio. Fertile. Soil. 2: 151-155.

Bahattacharyya, T., Pal, D.K., Mandal, C., and Velayutham, M. (2000). Organic carbon stock in Indian soils and their geographical distribution. National Bureau of Soil Survey and Land Use Planning. Current Science, 79(5):655-660

Balaji M. Krishna-Reddy, B. Jogeswar, G. Reddy, L. A. and Kavi-Kishor, P.B. (2003). Alleviating effect of citrate on aluminum toxicity of rice seedlings. Department of Genetics. Osmania University. Hyderabad 500007. India Current Science. 85: 3(10).

Baldock, J.A and Skjemstad, J.O (1999). Soil organic carbon/soil organic matter. In: soil analysis: An interpretation manual. CSRIO publishing, Victoria, Australia. Eds. K.I. Peverill, L.A. Sparrow and D.J. Reuter. Pp 159-170.

Bardgett, R.D. (2011). Plant–soil interactions in a changing world. F1000 Biology Reports 2011, 3:16 (doi:10.3410/B3-16)

Barker, B.J., Fausey, N.R., and Islam, K.R. (2004). Comparison of soil physical properties under two different water table management regimes. Soil Sci. Soc. Am. J. 68:1973-1981.

Barker, J.M., Ochsner, T.E., Venterea, R. T. and Griffis, T.J. (2007). Tillage and soil carbon sequestration – what do we really know? Agriculture, Ecosystems and Environment. 118, 1-5.

Barros, E., *et al.*, (2003). Development of the soil macro fauna community under silvopastorial and agro-silvicultural systems in Amazonia, Pedobiologia, 47, 1273-1280

Batjes, N.H., (1992). Organic matter and carbon dioxide. In : A review of soil factors and processes that control fluxes of heat, moisture and greenhouse gases, Pp. 97 -148 (eds. N.H Batjes and E.M. Bridges). Technical paper 23, International Soil References and Information Center, Wageningen.

Batjes, N.H., and Bridges, E.M., (1993). Soil vulnerability to pollution. Soil Use and Management, 9: 25-29.

Batjes, N.H., (1996). Total carbon and nitrogen in the soils of the world. International Soil Reference and Information Center (ISRIC). European Journal of Soil Science. 47: 151-163.

Batjes, N.H (1999). Management options for reducing CO_2 concentrations in the atmosphere by increasing carbon sequestration in the soil. ISRIC Technical paper, 30: 114

Batjes, N.H., and Sombroek, W.G. (1997). Possibilities for carbon sequestration in tropical and subtropical soils. Glob. Change. Boil. 3: 161-173.

Blatt, H., and Robert J. T. (1996) . Petrology*:* Igneous, Sedimentary and Metamorphic, 2nd ed., Freeman, pp. 281–292

Bell, M.J., Moody, P.W., Yo, S.A and Connolly, R.D. (1999). Using active fractions of soil organic matter as indicators of the sustainability of ferrosol farming system. Aust. J. Soil Res., 37: 279-287.

Bennie, A.T.P., and Bolta, F.J.P. (1986). Effect of deep tillage and controlled traffic on root growth, water use efficiency and use of irrigated maize and wheat. Soil Tillage Research 7: 85-95

Bernoux, M., Carvalho, M.D.S, Volkoff, B., and Serri, C.C. (2002). Brazils soil carbon stocks. Soil Science Society of American Journal; 66:b 888- 896

Binkley, D and Hart, S. (1989). Components of nitrogen availability assessments in forest soils. Advance soil science10:57-116.

Blair, G.J., Lefroy, R.D and Lisle, L. (1995). Soil carbon fractions based on their degree of oxidation and the development of a carbon management index for agricultural systems. Aust. J. Soil Res., 46: 1459-1466.

Blair, N and Crocker, G.J. (2000). Crop rotation effects on soil carbon and physical fertility of two Australian soils. Aust. J. Soil Res., 38: 71-84.

Blair, N., Faulkner, R.D., Till, A.R and Prince, K.F. (2003). The impact of plant residues with different breakdown rates on soil carbon and soil structure. In. proc. 16th ISTRO Conference, 13-18 July, Brisbane, Australia. Pp 175-181.

Bolin, B., Sukumar, R., Ciais, P., Cramer, W., Jarvis, P., Kheshgi, H., Nobre, C., Semonov, S., and Steffen, W., (2000). Global paspective. In: Watson, R., Noble, I., Bolin, B., Ravindranth, N., D.J.V. Dokken (eds.). Land use, land use change, and forestry. Cambridge University Press. Cambridge, Pp 23-52.

Boomie,O.(1998). Motherland Nigeria. Geography http://www.motherlandnigeria.com/geography.html.

Boserup, E., (1965). The condition of agricultural growth, Earthscan publications, London.

Bosquet, P, Peylin, P, Ciasis, P, Quere, C.L, Fredling-stein, P and Tans, P.P. (2000). Regional changes in CO_2 fluxes of land and ocean since 1980. Science 290: 1342-1346.

Brahim, N., Bernoux, M. R, Blavet, D and Gallali, T.P. (2010). Tunisian soil organic carbon stock. International Journal of Soil Science 5(1): 34-40.

Brams, E.A (1971). Continuous cultivation of West African soils: organic matter diminution and effects of applied lime and phosphorus. Plant and Soil 35: 401- 414.

Bremner, J.M. and Mulvaney, C.S. (1982). Total-Nitrogen. In: Methods of Soil analysis, Part 2. A.L. Page, R.H. Mille and D.R. Keeney (eds). American Society of Agronomy Madison, W1 pp 595-624.

Bremner, J.M., and Keeney, D.R (1965). Steam distillation methods for determination of ammonium, nitrate and nitrite. Anal. Chem. Acta 32 163-215.

Brennan, S.T., Buruss, R.C., Merrill, D.M., Freeman, P.A., and Ruppert, L.F. (2010). A probabilistic assessment management for the evaluation of geologic carbon dioxide storage. U.S Geological Survey Open-File Repot. 1127: 31

Brito, L.F., La Scala Jr., N., Merques Jr., J. and Pereira, G.T. (2005). Variabilidade temporal da emissao de CO_2 do solo e sue relacao com a temperature do solo em differentes posicoes na paisgem em area cultivada com cana-de acucar. In: simposio sobre plantio direto e Meio ambiente; sequestro de carbono e qualidade da agua, pp 210-212. Anais Foz do Iguacu, 18-20 de Maio 2005.

Bronick, C.J and Lal, R. (2004). Soil structure and management: A review: Geoderma, 124:3-22.

Bruce, J.P., Frome, M., Haites, E., Janzen, H., Lal, R., and Paustian, K. (1999). Carbon sequestration in soils. Journal of soil and water conservation, 54 :382-389.

Bulluck, L.R., Brosius, M., Evanylon, G.K., and Ristaino, J.B. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties in organic and conventional farms. Applied Soil Ecology 19,147 – 160.

Buol, S.W, Hole, F.D, McCracken, R.J and Southard, R.J. (1997). Soil genesis and classification. 4th edition. The IOWA State University press. Ames. IOWA 360 pp.

Burke, I.C, Ynker, N.M. Parton, W.J. Cole, C.V. Flach, K. and Chimel, D.S. (1995). Texture, climate and cultivation effects on soil organic matter content in U.S grassland soils. Soil Science Society of American Journal 53: 800-805.

Burruss, R.C., and Brennan, S.T (2003). Geologic sequestration of carbon dioxide – An energy resource perspective. U.S Geologic Survey Facts Sheet – 026.

Brye, K.R and Kucharik, C.J. (2003). Carbon and nitrogen sequestration in two prairie topo-chronosequence on contrasting soils in southern Wisconsin. Am. Midl. Nat. 149: 90-103

Calegari, A., and Alexander, I. (1998). The effects of tillage and cover crops on some chemical properties of an oxisols and summer crop yields in south-western Parana, Brazil. Adv. Geo. Ecol., 31: 1239-1246.

Cannel, M.G. (2003). Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacity globally in Europe and the UK. Biomass and bio-energy, 24, 97-116. carbon in southern new England hardwood forest landscapes. Soil Science Society of American Journal, 68:895-903.

Castro Filho, C., Muzilli, O. and Podanoschi, A.L. (1998). Estabilidade dos agregados e sua relacao com o teor de carbon organic num latossolo roxo distrofico, em funcao de sistemas de plantio, rotacoes de culturas e metodos de preparo das amostra. Rev. Bras. Cien. Solo, 22 :527-538.

Cerri, C.E.P., Easter, M., Paustian, K., Killian, K., Coleman, K., Bernoux M. *et al*. (2007). Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030. *Agriculture*, *Ecosystem & Environment*, 122, 58 – 72.

Chae, Y.M. and Tabatabai, A. (1986). Mineralization of N in soils amended with organic wastes. Journal of environmental quality 15:193-198.

Chan, K.Y and Partley, J. (1998). Soil structure decline-how the trend can be reversed? In: agriculture and environmental imperative; Eds. J. Partley and A. Robinson CSIRO; Collingwood, Australia.

Chan, K.Y. (2001). Soil organic carbon and soil structure: implications for the soil health of agro-systems. In soil health. The foundation of sustainable agriculture. Proc. Of a workshop on the importance of soil health in agriculture. Ed. R. Lines-kelly, Wollongbar Agric. Institute NSW PP 126-133.

Chan, K.Y., Heenan, D.P., Grabski, A.S and So, H.B (1998). Soil carbon sequestration and changes in soil quality under conservation tillage on lighter-textured soils in Australia. In: conservation tillage. Can it assist in mitigating the greenhouse gas problem? Symposium organized by Australian soil science society Inc and international soil tillage research organization. 30th April 1998, University of Queensland, St Lucia.

Chesworth W. (2008). Encyclopedia of Soil Science, springer, Dordrecht, The Netherlands

Chikezie, A., Eswaran, H., Asawalam, D.O., and Ano, A.O. (2009). Characterization of the benchmark soils of contrasting parent materials in Abia State, South-eastern Nigeria. Global J. of Pure and Applied Sciences 16(1) 23-29.

Chude, V.O., Malgwi, W.B., Ampu, I.Y., and Ano, A.O. (2011). Manual on Soil Fertility Assessment. Federal Fertilizer Department. FAO and National Programme on Food Security, Abuja, Nigeria. 62.

Chukwu, G.O. (2013). Soil Survey and Classification of Ikwuano Abia State, Nigeria, Journal of Environmental Science and Water Resources 2(5), 150 – 156.

CIA World Factbook (1991). **Nigeria Land Use, Soils, and Land Tenure.** The Library of CongressCountryStudies; http://www.photius.com/countries/nigeria/economy/nigeria_economy_land_use_soils_ad~10013.html

Cleaver, K.M. and Schreiber (1994). Reversing the spiral. The population, agriculture and environment nexus in Sub-Sahara Africa; World bank. Washington D.C

Cossey, D.A., Thomason, W.E., Muller, R.W., Wynn, K.J., Woolfolk, C.W., Johnson, G.V and Raun, W.R. (2002). Relationship between ammonium and nitrate in wheat plant tissue and estimated nitrogen loss. Journal of Plant Nutrition, 25(7), 1429-1442.

Dala, R.C. and Mayer, R.J. (1986a). Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. Overall changes in soil properties and trends in winter cereal yields . Aust. J. Soil Res., 24, 265-279.

Dalal, R.C and Mayer, R.J. (1986b). Long-term trends in fertility of soils under continuous cultivation and cereal cropping. 11b total organic carbon and its rate of loss from the soil profile. Australian J. of soil resource 24: 281-292.

Dalal, R.C. and Chan, K.Y. (2001). Soil organic matter in rainfed cropping systems of Australian cereal belth. Australian Journal of Soil Research 39: 435-464.

Davidson, E.A and Ackerman, I.L (1993). Changes in soil carbon inventories following cultivation of previously untilled soil. Biogeochemistry, 20: 161-193.

Davidson, E.A. and I.A. Janssens. (2006) Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, **440**, 165–173.

Deekor, T.N., Iwara, A.I., Ogundele, F.O., Amiolemen, S.O., and Ita, A.E. (2012). Changes in soil properties under different land use covers in parts of Odukpani, Cross River State Nigeria. Journal of Environment and Ecology 3(1). 87-99.

Deizman, M.M., Mostaghini, S., Schanholtz., V.O., and Mitchell, J.K. (1987). Size distribution of eroded sediment from two tillage sustems. Trans. ASAE 30, 1642-1647.

Del –grosso S.J, How Orson A.D. and Parton W.J. (2005). Testing day lent model stimulations of corn yield and nitrous oxide emissions in irrigated tillage system in colorado. J. Environ. Qual.37:1363 – 1389.

Denef, K., Six, J., Mercks, R., andPaustian, K. (2004). Carbon sequestration in microaggregates of No-tillage soils with different clay mineraology. Soil, Sci. Soc. Am. J. 68:1935-1944.

Diaz-Zorita, M., Perfect, E and Grove, J.H. (2002). Descriptive methods for assessing soil structure. Soil and Tillage Research 64: 3-22.

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

Dinc, U., Ozbek, H., Kapur, A.S., and Senol, S. (1987). Toprak genesisi ve Eastern States, Ethiopia publishing house Benin. Pp 33-34.

Donahue, R.L., Miller, R.W. and Shickluna, J.C. (1990) Soils: An introduction to soil and plant growth (5th ed.). New Delhi: Prentice Hall of India. 667 pp.

Doyne, H.C., Hartley K.T., Watson W.A. (1938). Soil types and manorial experiments in Nigeria. West Africa Agricultural Conference, Lagos. Pp 227 – 298.

Dupriez, H and P. Deleener, (1992). Way of water: Run off irrigation and Drainage. The

Macmillian press ltd. London.

Driessen, P., Deckers, J., Spaargaren, O., and Nachtergaele, F. (2001). Lecture notes on the major soils of the world. Rome: FAO.

Dudal, R. (1996). A World Reference Base for Soil Resources; Background, Principles and Challenges. Proc. Inter. WRB Workshop, Pretoria, p 6.

Edeth, A.E., Oden, M.I. Efretuei, O.E. (1994). Correlation between cone penetration resistance and standard penetration in parts of the Coastal plain sand, South-eastern Nigeria. Bulletin of the International Association of Engineering Geology No. 49, 41 – 49.

Edwards, J.H., C.W. Wood, D.L. Thurlow and M.E Ruf. (1992). Tillage and crop rotation. effects on fertility status of a hapludult. Soil Sci. Soc. Am. J. 56: 1577-1582.

Ekundayo, E.O. (2004). Influence of different soil types on abundance of vesicular-arbuscular mycorrhizal fungi in arable soils of southern Nigeria. Nigeria journal of soil science, 14, 40-47.

Eliasson, P. (2007). Impact of climate change on nitrogen and carbon cycles in boreal forest ecosystems. Doctorial thesis, Swedish University of Agricultural Science.

Elliot, L.F. and Lynch, J.M. (1984). The effect of available carbon and nitrogen in straw on soil and ash aggregation and acetic acid production. Plant soil, 78:335-343.

EPA, (2007). Class V experimental technology well guidance for pilot geologic sequestration project

Eshett, E.T. (1987) The basaltic soils of Southeastern Nigeria: Properties, classification and constraints to productivity. *Journal of Soil Science* 38(4): 565-571.

Eshett, E.T., Omoeti, J.A.I. and Juo, A.S.R. (1990) Physico-chemical, morphological and clay mineralogical properties of soils overlying basement complex rocks in Ogoja, Northern Cross River State of Nigeria. *Soil Science and Plant Nutrition* 36(2): 203-214.

Eshett, E.T. (1991). Socio-economic and edaphic factors of small scale arable crop production in Southeastern Nigeria: A case study of Eziobodo Farming Community. *Agronomie Africaine* 3(1): 23-33.

Eshett, E.T. (1993). The wetland soils of Nigeria: properties, classification and traditional land use practices. In: B. Gopal, A. Hillbricht-Ikowasko and R.G. Wetzel (eds). Wetlands and Ecotones: Studies of land-water interactions. New Delhi: National Institute of Ecology in conjunction with International Scientific Publications. Pp 227-224.

Esu, I.E. and Ojanuga, A.G. (1986). Soil characterization studies within the natural levees of River Kaduna, Nigeria. Nigerian Journal of Soil Science 6: 1-13.

Esu, I.E. (1991). Detailed soil survey of NIHORT farms, Nigeria Institute for Agricultural Research, Ahmadu Bello University, Zaria.

Esu, I.E. (1999). Fundamentals of pedology. Sterling Horden Publishers Nigeria Ltd, Ibadan, Nigeria. 209 pp

Esu, I.E. (2004). Soil characterisation and mapping for food security and sustainable environment in Nigeria. A Keynote address presented at the *29th Annual Conference of the Soil Science Society of Nigeria* held at the University of Agriculture, Abeokuta Nigeria. Pp. 9-18.

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

Eswaran, H., Berg, E.V.D and Reich, P., (1993). Organic carbon in soils of the world. Soil Science Society of American Journal, 57:192-194.

Eswaran, H, Berg, E.V.D., Reich, P. and Kimble J. (1995). Global soil carbon resources. In: soils and Global change. Eds. R, Lal, J. Kimble, E. Levine and B.A Stewart, CRC, Lewis publishers pp 27 – 29.

Evers, G., and Agostini, A. (2000). No-tillage farming for sustainable land management. Lessons from the 2000 Brazil Study Tour. Rome, Italy: FAO.

Fagbami, A.A. and Ogunkunle, O.O. (2000) Soil survey, land evaluation and agronomy: The Nigerian case study. *In:* Agronomy of Nigeria. Pp. 165-173.

FAO (Food and Agricultural Organization) (1984). Tillage systems for soil and water conservation. FAO Soils Bulletin No. 54. Rome.

FAO (Food and agricultural organization) (1998). Guidelines for soil profile description. 2nd edition. Rome 66pp.

FAO (Food and agricultural organization), International Soil Reference and Information Center (ISRIC), International Society of Soil Science (ISSS) (1998). Word Reference Base for Soil Resources. Rome, Italy, FAO-SSS-ISRIC, Word Resources Reports 84 and 91

FAO (Food and Agricultural Organization) (2001). Soil carbon sequestration for improved land management, World Soil Resources Report. 96 Rome.

FAO (Food and Agricultural Organization) (2002). Land and agriculture; A compendium of recent sustainable diminitiatives in the field of agric and land management 57 pp.

FAO (Food and Agricultural Organization) (2004). Carbon sequestration in dry land soils, World Soil Resources Report. 102, Rome.

FAO (Food and Agricultural Organization) (2005). The importance of soil organic matter. Key to drought resistant soil and sustained food production. FAO soils bulletin no. 80. 78pp.

FAO (Food and Agricultural Organization) (2006). World reference base for soil resources 84 World Soil Resources Report, ISSS-AISSIBG, FAO Rome, Italy.

FDALR [Federal Department of Agricultural Land Resources] (1985). The reconnaissance soil survey of Imo State (1: 250, 000). Owerri: Federal Department of Agricultural Land Resources. 133 pp.

Federal Department of Agricultural Land Resources (FDALR) (1990). The reconnaissance Soil Survey of Nigeria. Soils Report. Volume 4. 377pp

FDALR (Federal Department of Agricultural Land Resources) (1999). Soil map of Nigeria. fertility degradation in the Coastal plain of Tanzania. Land degradation and rehabilitation, 6: 215-221

FGN [Federal Government of Nigeria] (1997) Natural resource aspects of sustainable development in Nigeria. Presented at the *5th session of the United Nations Commission on Sustainable Development*. [Available from: http://www.un.org/esa/agenda21/natlinfo/countr/nigeria/index.htm] Last Update: 1 April 1997 [Accessed: 1 April 2008]

FPDD (Fertilizer Procurement and Distribution Division). (1990). Literature Review on Soil Fertility Investigations in Nigeria. Produced by the Federal Ministry of Agriculture and Natural Resources, Lagos.

Fisher, M.J., Rao, I.M., and Ayarza, M.A. (1994). Carbon storage by introduced deep-rooted grasses in the South America Savannas . Science, 371: 236 – 238.

Folarin, O.O. (2011). Soil Survey Perspective and problems in Nigeria. Soil Survey horizons: Student article contest, University of Ibadan, Ibadan, Oyo State, Pp10.

Follett, R. F., Kimble, J., and Lal, R. (2001). The potential of US grazing lands to sequester carbon and mitigate the greenhouse effect. CRC Press, Boca Raton, Florider.

Follet, R.F. (2001). Soil management concept and carbon sequestration in crop land soils. Soil tillage Research, 61: 77-92

Forge Frédéric (2001). Carbon sequestration by agricultural soil. Science and Technology Division. Pp 16.

Forley, I.A., *et al* (2005). Global consequences of land use. Science 309: 570-574.

Foth, H.D. (1984. Fundamentals of soil science. Seventh edition, John Willey and Sons, New York. 435pp

Foth H.D (1990). Fundamental of Soil Science. John Wiley & Sons New York, M, USA, 8th edition

Foth, H.D. (2006). Fundamentals of Soil Science. 8th Edition. New York: John Wiley & Sons

Friessen, D.K. (1991). Fate and efficiency of sulfur fertilizer applied to food crops in West Africa. Kluwer Academic Publisher. Dordrecht, Netherlands pp 59-68.

Gal, A., Szeg, T., Simon, B., Szeder, B., Micheli, E., Etelka, T., Zoolnay, A., and Akagi, J (2006). Indicators of soil degradation process on a chernozem field in Hungary. Proc. Of 18th World Congress of Soil Science. July 9-15 Philadephia Pennsylvania, U.S.A.

Gale, W.J., Cambardella, C.A., and Bailey, T.B. (2000). Root-derived carbon and the formation and stabilization of aggregates. Soil Science. Society of American Journal 64: 201-207.

Gee, G.W. and D. Or. (2002). Particle size analysis. In: J.H. Dane and G.C. Topp (eds). Methods of soil analysis, part 4. physical methods. Soil Science Society of America. Book series . No. 5 ASA and SSA Madison, W1, pp 255-293.

Gibson, T.S., Chan, K.Y., Sharma, G., and Shearman, R. (2002). Soil carbon sequestration utilizing recycled organics. A review of the scientific literature. NSW Agriculture. Pp 74.

Govaerts, B., Sayre, K.D., Lichter, K., Dendooven, L., and Deckers, J. (2007). Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems. Plant Soil 291:39-54

Grace, P.R, Colunga-Gracia, M, Gage, S.H, Robertson, G.P, and Safer, G.R. (2006). The potential impact of agricultural management and climate change on soil organic carbon of the Northern Central Region of the United States. Ecosystem 9: 816-827

Grant, R.F., Juma, N.G., Robertson, J.A., Izaurralde, R.C., and McGill, W.B. (2001). Long term changes in soil carbon under different fertilizer, manure and rotation: testing the mathematical model ecosystem with data from the Breton plots. Soil Science Society of American Journal, 65: 205-214.

Gray Jonathan and Murphy Brain (2002). Parent material and world soil distribution. Dept of Land and Water Conservation, NSW. Australia. Symposium no. 21. 2215-1-2215-13.

Gregorich, E.G, Carter, M.R., Angers, D.A., Monreal, C.M., and Elliot, B.H., (1994). Towards a minimum data set to asses soil organic matter quality in agricultural soils. Canadian J. Soil Sci. 74: 367-385.

Grossman, R.B and Reinch, T.G. (2002). Bulk density and linear extensibility in: methods of soil analysis part 4. Physical methods. Dane, J.H and G.C. Topp (eds). Soil Science Soc. Am. Book series No. 5. ASA and SSA Madison, W.I, Pp: 201-228.

Guo, L.B and Gifford, R.M. (2002). Soil carbon stocks and land use change: a meta analysis. Global Change Biology 8, 345-360

Hallsworth, E.G and H.D. Waring. (1964). An alternative hypothesis for the formation of the solidized-solonetz of the Pilliga District. Journal of Soil Science 15:158-177

Halving, J.I., James, D.B., Samuel, L., Tisdale and Werner, L.N. (2005). Soil fertility and fertilizer. An introduction to nutrient management. 7th Edition. Prentice, New Jersey Delhi. Pp 515.

Hayney, R.L., Franzluebbers, A.J., Porten, E.B., Hons, F.M., and Zuberer. (2004). Soil carbon and nitrogen mineralization. Influence of drying temperature. Soil Science Society of American Journal 68:489-492

Hartemink, A.E and Bridges, E.M. (1995). The influence of parent material on soil fertility degradation in the coastal plain of Tanzania. Land degradation and rehabilitation, 6: 215-221

Hassink, J. (1992). Effects of soil texture and structure on carbon and nitrogen mineralization in grassland soils. Biology and fertility of soils. 14: 126-134.

Hauck, R.D. (1984). Nitrogen in crop production. American society of agronomy, Madison, Wis.

Haung, W.Z. and Shoenau, J.J. (1996). Forms, amounts and distribution of Carbon, Nitrogen, Phosphorus and Sulphure in a boreal aspen forest soil. Canadian Journal of Soil SC. Pp 373-385.

Haynes RJ and Swift, R. S. (1990). Stability of soil aggregates in relation to organic constituents and soil water content. J. Soil Sci. 41: 73-83.

Haynes, R.J. and Naidu, R. (1998). Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutrient cycling in Agro-ecosystems, vol.1, 123-137

Hayness, R.J., Dominy, C.S, and Graham, M.H. (2003). Effect of agricultural land use on soil organic matter status and the composition of earthworm communities in Kwazulu-Natal South Africa. Agric. Ecosystem. Environment. 95:453-467.

Herbert, B. (1996). Dictionary of Geotechnical Engineering, English, German, Springer. 61pp

He, N., Yunhai, Z., Dai, J., Han, X., Baoyin, T and Yu, G. (2012). Land use impact on soil carbon and nitrogen sequestration in typical steppe ecosystems, Inner Mongolia. Journal of Geographical Science. 22(5): 859-873.

Heenan, D.P., Chan, K.Y., and Knight, P.G. (2004). Long term impact of rotation, tillage and stubble management on the loss of soil organic carbon and nitrogen from a chromic luvisol. Soil Till, Res. 76: 59-68.

Hirel, B., Tetu, T., Lea, P.J and Dubois, F (2011). Improving nitrogen use efficiency in crops for sustainable agriculture. Sustainability, 3. 1452-1485.

Hodges, S.C. (2012). Soil fertility basics. Soil Science Extension. North Carolina State University. Pp73

Hook, J.E. (1981). Movement of phosphorus and nitrogen in soil following application of municipal wastewater. In - Chemical mobility and reactivity in soil systems, ed. D. w. Nelson., D.E. Elrick and K. K. Tanji. Soil Science Society of America, Madison, pp. 241-255.

Hopkins, D.W., Waite, J.S., McNicols, J.W., Poulton, P.R., Macdonlad, A.J. & O’Donnell, A.G. (2009). Soil carbon contents in long-term experimental grassland plots in the UK (Palace Leas and Park Grass) have not change consistently in recent decades. *Global Change Biology,* **15**, 1739 – 1754.

Hoyt, G.D., and Hargrove, W.H. (1986). Legume cover crops for improving crop and spoil management in the southern United states. Horticultural science. 21: 397- 402.

Huange, P.M., and Violante, A. (1986). Influence of organic acids on crystallization and surface properties of precipitation products of aluminum: In interactions of soil minerals with natural organic and microbes, P.M., Huange and M. Schnitzer, eds. SSSA Special publication, Madison, Wisconsin, 17,159-221.

Ibeneme, S.I, Ibe, K.K., Selemo, A.O., Udensi, S.C., Nwagbara, J.O., Eze, I.O., Ubechu, B.O., Onwuka, C.O (2013). Geoelectrical Assessment of a proposed dam site around Ehuhe area of Orji River South-eastern Nigeria. Journal of Natural Sciences Research 3(13) 163 -170

Idigbor, C.M., Asawalam D.O., and Agbede O.O., (2008). Phosphorus forms and P sorption Capacity of Fauna Modified Soils of South-Eastern Nigeria. Journal of Agricultural Production and Technology. 4 (2): 195-210.

Idoga, S and Azagaku, D.E. (2005). Characterization and classification of soils of Janta area, Plateau State of Nigeria. J. of Soil Sci. 15:116-122.

Igbozuruike, M. U. (1975). Vegetation types. *In:* Nigeria in maps: Eastern States. G. E. K. Ofomata (ed.). Benin City: Ethiope Publishing. Pp. 30-32.

Igwe, C.A., Akamigbo, F.O.R. and Mbagwu, J.S.C. (1999). Chemical and mineralogical properties of soils in southeastern Nigeria in relation to aggregate stability. Geoderma, 92: 111-123.

Inoue, K., and Huange, P.M. (1986). Influence of selected ligands on the formation of allophone and imogolite: Soil Sci. Soc. Am. J.50, 1623-1633.

IOWA Soybean Association 2008. Understanding soil Nitrogen dynamics. Agronomic research and economic performance on farm network. Pp 12. www.isafarmnet.com.

(IPCC) Intergovernmental Panel on Climate Change, (1990). Climate change (eds. J.T. Houghton, G.J. Jenkins and J.J. Ephraums), Cambridge University Press Cambridge.

(IPCC) Intergovernmental Panel on Climate Change (1992). Climate change. The supplementary report to the IPCC scientific Assessment (eds. J.T. Houghton, B.A. Callander and S.K Verney). Cambridge University Press.

(IPCC) Intergovernmental Panel on Climate Change (2000). Land use, land use change and forestry. Cambridge Univ. Press, Cambridge. UK

(IPCC) Intergovernmental Panel on Climate Change (2005). Special report on CO_2 storage, special report of the Intergovernmental Panel on Climate Change

Irmak, S, Surueu, A.K and Aydogdu, L.H. (2007). Effects of different parent material on the mineral characteristics of soils in the Arid Region of Turkey. Pakistan J. of Biological Sciences 10(4):528-536.

Isirimah, N.O., Dickson, A.A.and Igwe, C..I.A. (2003). Introductory soil chemistry and biology for agriculture and biotechnology. OSIA Int'L publishers ltd port Harcourt 269pp.

Islam K.R and Weil R.R (2000) Land use effects on soil quality in a tropical forest ecosystems of Bangladesh. Agricultural Ecosystems and Environment 79, 9-16.

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

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

Izaurralde, R.C and Cerri, C.C. (2002). Organic matter management. In: Encyclopedia of soil science, pp. 910-916. New York, USA, Marcel Dekker Inc.

Janssens, I.A., Freibauer, A., Ciais, P., Smith, P., Nabuurs, G.J., Folberth, G., Schlamadinger, B., Hutjes., R. W. A., Ceulemans, R., Schulze, E.D., Valentini, R., and Dolman, AJ. (2003). Europes terrestrial biosphere absorbs 7 to 12 percent of European anthropogenic CO_2 emission. Science 300, 1538-1542.

Jansson, S.L., and Persson, J. 1(982). Mineralization and immobilization of soil nitrogen. In nitrogen in agricultural soils. Ed. F.J. Stevenson. American society of agronomy, Madison WI. Pp. 229-252.

Jenkinson,D.S.(1991). The Rothamsted long-term experiment are they still of use? Agron J.83: 2.

Jenny, H. (1980). The Soil Resource-Origin and Behavior. Springer-Verlag, New York.

Jobbagy, E. G., and Jackson, R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological application 10: 423-436.

Johnson, D.W and Curtis, P.S. (2001). Effect of forest management on soil carbon and nitrogen storage. Meta analysis for ecology management. 140: 227-238.

Johnston, A.E., Poulton, P.R. and Coleman, K. (2009). Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. Advances in Agronomy. 101: 1-57.

Jungerius, P.D and Levelt T. W.W. (1964). Clay Mineralogy of Soil over Sedimentary Rocks in Eastern Nigeria, Science Vol 97, No.2

Jungerius, P.D. (1964). Soils of Eastern Nigeria. Publ. serv. Goal. Luxembourg 14: 185 – 198.

Juo, A.S.R., and Kang, B.T., (1989). Nutrient effect of modification of shifting cultivation in West Africa, pp289-299.

Juo, A.S.R., Franzluebbers, K., Dabiri, A. and Ikhile, B. (1995). Changes in soil properties during long term fallow and continuous cultivation after forest clearing in Nigeria. Agriculture ecosystems and environment. 56:9-18.

Kaiser, K., and Guggenberger, G. (2003). Mineral surface and soil organic matter. Euro. J. Soil Sci. 54: 1-18.

Keeney, D.R., and Nelson, D.W. (1982). Nitrogen-inorganic forms. P.643-698. In A.L.

Kemper, W.D and Rosenau, R.C. (1986). Size distribution of aggregates. In: Method of soil analysis. A. Klute. Ed. Part 1 2nd edition. Agron. Monogr. 9. ASA.SSSA. Madison. W.I. pp 425-442.

Kimigo, J., Gichern, P.T., Mbuvi, J.P and Kironchi, G (2008). Effects of land use change on soil qualities in the Sasumua catchment of Tana river drainage system in Nyandaarau District, Kenya East Africa. Agric. Journal 74(2). 85-94.

Kings, K.F.S. (1979). Agro-forestry and utilization of fragile ecosystem for ecology management. 161-168.

King, J.A., and Campell, B.M. (1994). Soil organic matter relations in five land cover types in the Miombo region. Forest Ecology and Management 67, 225-239 .

Knops, J.M.H. and D. Tilman, 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. Ecology 81: 88-98.

Kong, A.Y., Six, J.,Bryant, D.C., Denison, R.F and Van Kessel, C. (2005). The relationship between carbon input, aggregation and soil organic carbon stabilization in sustainable cropping systems. Soil Sci. Soc.AM. J. 69:1078-1085.

Koositra, M.J., Juo, A.S.R., and Schodnderbeek, D. (1990). Soil degradation. In: cultivated Alfisols under different management systems in Southwestern Nigeria. In: soil micro-morphology: A basic applied science, Douglas, L.A (ed.). Elservier, Amsterdam, the Netherlands pp 61-69.

Koutika, L.S., Bartoli, F., Andreux, F., Cerri, C.C., Burtin, G., Chone, T., Philippy, R. (2002). Organic matter dynamics and aggregation in soil under rain and pastures of increasing age in the Eastern Amazon Basin. Geoderma 76, 87-112.

Kurkova M., Klika, Z., Klikova, C.H. and Havel, J.. (2004). Humic acids from oxidized coal 1. Elemental compositon, titration curves, Heavy metals in HA simplex, nuclear magnetic resonance spectra of HAs and infrared spectroscopy chemosphere 54: 1237 -1245.

Lal, R. (1990). Soil erosion in the tropics; principles and management. McGraw-Hill Inc. Pp 1-250.

Lal, R. (1999). Global carbon pools and fluxes and the impact of agricultural intensification and judicious land use. Pp 45 – 52 In: prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable land management with a focus on latin Americ and the Caribbean.

Lal, R. and Bruce, J. (1999). The potential of world crop land soils to sequester carbon and mitigate the green house effect. Environmental Science and Policy. 2:177-185.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304: 1623-1627.

Lal, R. (2005). No-till farming and environment quality. In: symposio sobre plantio direto e Meio ambient; sequestro de carbon e qualidade da agua, pp 29-37. Anais. Foz do Iguacu, 18-20 de Maio 2005.

Lal, R., (2007). Soil science and the carbon civilization. Soil Sci. Soc. Am. J. 71:1425-1437. land use practices. In: B. Gopal, A. Hillbricht-Ikowasko and R.G. Wetzel (eds). Wetlands and Ecotones: Studies of land-water interactions. New Delhi: National Institute of Ecology in conjunction with International Scientific Publications. Pp 227-224.

Landon, R. (1991). Booker tropical soil manual: A handbook for survey and agricultural land evaluation in the tropics and subtropics. Longman Inc., New York.

Law-Ogbomo, K.E., and Nwachokor, M.A. (2010). Variability in selected soil physico-chemical properties of five soils formed on different parent materials in south-eastern Nigeria. Research Journal of Agriculture and Biological Sciences. 6(1):14-19.

Leary, M.O., George, R and Michael S. (1994). Understanding nitrogen in soils. University of Minnesota 89-EWQI – 1-9180.

Legros, J.P., Loveland, P.J. and Rounsevell, M.D.A. (1994). Soils and climate change – where next? In : Soil responses to climate change, Pp 258 – 266 (eds. M.D.A. Rounsevell and P.J. Loveland). NATO ASI Series vol. 23, Springer-Verlag, Berlin.

Lekwa, G and Whiteside (1986). Coastal plain soils of southeastern Nigeria: 1. Morphology, classification and Genetic relationships. Soil Science Society of American Journal. 50:154-160.

Lichter, K., Govaerts, B., Six, J., Sayre, K.D, Deckers, J., and Dendooven, L.(2008). Aggregation and carbon and nitrogen contents of soil organic matter fractions in the permanent raised-bed planting systems in the Highlands of Central Mexico. Plant Soil, 305:237-252. Management, 9: 25-29.

Linda, H., John, K., Richard, B., and Rattan, L. (2003). The potential of US forest soil to sequester carbon. Chapter 23 in Kimble, M., Health, S., Richard, B., and Rattan, L. (Eds). The potential of US forest to sequester carbon and mitigate the green house effect, CRC Press. Pp 385-394

Loide, V. (2004). About the effect of the contents and ratios of soils available Ca, K and Mg in liming of acid soil. Agricultural Research Center, Teaduse 4/6. Agronomy Research 2 (1), 71-82.

Madueke, C. O., Asadu, C.L.A. Eshett, E.T. Akamigbo, F.O.R. Maduekeh, E.C.C. Onyeokoro, C. Maduka, E.I. Obi, P.C.and Okene, C.D. (2012). Characterization and classification of soils on a toposequence formed from the Coastal plain sands of South-eastern Nigeria. Proceedings of Soil Science Society of Nigeria

Malgwi, W.B., Ojanuga, A.G., Chude, D.O., Kparmwang, T. and Raji, B.A. (2000). Morphological and physical properties of some soils of Samaru, Zaria, Nigeria. J. of Soil Research. 1:58-64.

Martens, D.A. (2000). Plant residue biochemistry regulates soil carbon cycling and carbon sequestratipon. Soil biology and biochemistry 32: 361-369

Matson, P.A., Parton, W.J., Power, A.G and Swift, M.J. (1997). Agricultural intensification and ecosystem properties. Science 277: 504-509.

Mbah, C.N. and F.I. Idike, (2011). Carbon storage in tropical agricultural soils of south eastern Nigeria under different management practices. International Research Journal of Agricultural Science vol. 1(2), 53-57.

Mbah, C.N and Mbagwu J.S.C (2003). Changes in structural stability and water retention of sandy clay loam amended with organic wastes. Journal of the Science of Agric, Food and Technology and the Environment.

Mbagwu, J.S.C and Obi, M.E. (2003). Land degradation, Agric productivity and Rural poverty. Environmental implication proceedings of 28th Annual Conference of the Soil Sc Soc of Nigeria at Umudike, Umuahia Nigeria 4-7 Nov 2003, pp 1-11.

Mclean, E. C., (1982). Aluminum in method of soil analysis (ed). C. A. Blacks. Agronomy No. 9 part 2 American Society of Agronomy, Madison Wisconsin.
methods of soil analysis part 4. Physical methods. Dane, J.H and G.C. Topp (eds). Soil Science Soc. Am. Book series No. 5. ASA and SSA Madison, W.I, Pp: 201-228.

Meixner, F.X and Yang, W.Y. (2006). Biogenic emissions of Nitric oxide and nitrous oxide from Arid and Arid-semi land. In: Dry land ecohydrology, Dvdorico, P. and A. Porporato (Eds.) Springer, Dordrecht, PP 233-255.

Metzi, R. (1991). Geography Guide, Sign up for my Newsletter. My Blog, my forum, sponsored lines visat Nigeria satellite broadband KU and C band unrivaled Service and prices. www.linksystems.UK.com.

Meyer, J.H., Van Antwerpen, R., and Meyer, E. (1996). A review of soil degradation and management research under intensive sugarcane cropping. Proc. S. Afr. Sug. Tech. Ass. 70, 22-28.

Michel, K.Y., Pascal, K.T.A., Souleymane, K., Jerome, E.T., Yao, T., Luc, A., and Danielle, B. (2010). Effects of land use types on soil organic carbon and nitrogen dynamics in Mid-West Cote d'Ivoire. European J. of Scientific Research 40(2): 211-222.

Miller C, (2000). Understanding the C:N ratio. ACRES, USA. A voice for Ecology-Agriculture. 30(4). 20pp.

Mills, A.G and Fey, M.V. (2003). Declining soil quality in South Africa: Effects of land use on soil organic matter and surface crusting. South African Journal of Science 99, 429-436.

Mielke, L.N and Schepers, J.S. (1986). Plant response to topsoil thickness on an eroded loess soil. Journal soil and water conservation 41: 59 -63.

Mokwunye, A.U., and Harmmond, L.L. (1992). Myths and science of fertilizer use in the tropics. In: myths and science of the soils of the tropics. Pub. No. 29, SSSA Madison Wisconsin, USA pp 121-134.

Moormann, F.R. 1977. Report of the committee on the classification of Alfisols and Ultisols with low activity clays In: Lekwa, G and Whiteside (1986). Coastal plain soils of southeastern Nigeria: 1. Morphology, classification and Genetic relationships. Soil Science Society of American Journal. 50:154-160.

Mucher, C.A., Stomph, T.J and Fresco L.O (1993). Proposal for good land use classification. FAO/ITC/WAS Rep. Wageningen Agricultural Univ. Dept. of Agronomy, Netherlands 37 pp.

Munsell soil colour (2009). Munsell Soil Colour Chart Revised edition. Macbeth Division of Kollmorgen Corporation, Baltimore, Maryland, USA, 2009.

Murphy L. and Riley, J. P., (1962). Modified single solution method for the determination of phosphate in natural water. Anal. Chem. ACTA 27: 31 - 36.

Nachtergaele, F.O., Spaargaren, O., Deckers, J.A., Ahrens, B., (2000): New developments in soil classification: World Reference Base for Soil Resources. Geoderma 96: 345-355

Nair, K.M., Venugopal K.R., Srinvas, S., and Seghal, J. (1999). Soil information processing application of Geographic Information System (GIS) Technology. Journal Indian Society of Soil Science 44(1): 115 – 122.

Nardi, S., Cucheri, G and Dell-Angolla, G. (1996). Biological activity of humus In: Piccolo, A.A (ed). Humic substances in terrestrial ecosystems. Elsevier, Amsterdam pp 361-406.

Nelson, D.W and Sommers, L.E. (1996). Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of American Book series. Nsukka. Pp 103.

NIMET (Nigerian Meteorological Agency), Nigeria,2008. Climate Weather and Water Information, for sustainable development and safety.

NRCRI (National Root Crop Research Institute) Umudike Meterological unit (2012) . Abia State Climate Data from 2008 – 2012.

Nuga, B.O (2001). Application of geographic information system for sustainable land resources management in Nigeria. Journal of Applied Chemistry and Agric. Res. Vol. 7 104 – 111.

Nuga, B.O., Eluwa, N.C., and Akinbola, G.E (2008). Characterization and classification of soils along a toposequence in Ikwuano LGA of Abia State Nigeria. Electronic Journal of Environment, Agriculture and Food chemistry. Pp2779-2788.

NSW (New South Wales) Department of Agriculture (2002). Interpreting soil tests for calcium, magnesium and calcium-magnesium ratios. Leaflet No. 7: 1-4.

Nyssen, J. , Temesgen, H., Lemenih, M, Zenedbe, A., Haregeweyn, N and Haile, M (2008). Spatial and temporary variation of soil organic stocks in a lake retreat area of the Ethopian right valley. Geoderma 146: 261-268

Obi, M.E. (1990). Soil physics: A compendium of lectures, University of Nigeria of human-induced soil degradation. An explanatory note 2nd revised edn. International Soil Reference and Information Center. Wageningen.

Obi, J.C. and Udoh, B.T. (2011). Identification of Soil management Factors from Spatially Variable Soil properties of Coastal plain sands in South-eastern Nigeria. Open Journal of Soil Science (1), 25 – 39.

Odunze, A.C. (2003). Northern Guinea Savanna soils and rainfall properties for erosion control and fertility improvement. Journal of African soils/African union (AU). Scientific technical and Research commission Lagos. Vol. 33: 73-82.

Offiong, R.A., Atu, J.E., Njar, G.N and Iwara, A.I (2009). Effects of land use change on soil physico-chemical properties in South-south Nigeria. African Journal of Environment, Pollution and Health 7(2), 47-51.

Ogban, P.I. and Ekerette, I.O. (2001) physical and Chemical Properties of the Coastal Plain Sands of Soils of South-eastern Nigeria. Nigeria Journal of Soil Research Vol. 2. Pp 6 – 14.

Oguike, P.C and Mbagwu, J.S.C. (2009). Variations in some physical properties and organic matter content of soils of coastal plain sand under different land use types. World journal of agricultural sciences 5(1): 63-69.

Ogunkunle, C.O and Awotoye, O.O. (2011). Soil fertility under different tree cropping systems in South western zone of Nigeria. Not. Sci. Biol., 3: 123 -128

Ohaeri, G.E.C (1961). Soil observation in Eastern Nigeria.

Ohiri, A.C., Ano, A.O., Chukwu, G.O. (1989). Characterization of Soils of Imo State in relation to crop production and fertilizer use. Annual Report National Root Crops Research institute Umudike, pp 49.

Ohu, J.U., and Folorunso, O.A., (1989). The effect of machinery traffic on the physical properties of sandy loamy soil and on the yield of sorghum in northeastern Nigeria. Soil Tillage Research, 13:399-405.

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

Ojanuga, A.G., Lekwa, G., and Akamigbo F.O.R (1981). Survey Classification and genesis of acid sands. In: Acid sands of South-eastern Nigeria. Soil Science Society of Nigeria, Special monography. No. 1 pp 1 – 18.

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

Okereke, C.N, Onu, N.N., Akaolisa, C.Z., Ikoro, D.O. Ibeneme, S.I., Ubechu, B., Chinemelu, E.S. and Amadikwa, L.O. (2012). Mapping gully erosion using Remote Sensory Technique. A case Study of Okigwe Area South eastern Nigeria. Journal of Engineering Research/Applications 2(3): 1955-1976

Okoye, E.O.U, Lekwa, G., Oparaugo, S.M.C, Olaniyi J.K., Ugwu, T.O., Ogunsola, A.O., Ucheagwu, H. M. and Ojanuga A.G. (1991). Soil map of Nigeria. Soil Survey and Land Evaluation Division. 374pp.

Olatilu, A.O and Oke, D.C. (2010). Potentials of multi-strata perennial-crop-based agro-forestry for carbon sequestration and climate change mitigation. Proc. of the 2nd Biennial National Conf. of the Forest and Forest Products Society. Akure 26th-29th April. Pp 238-242.

Oldeman, L.R., Hakkeling, R.T.A., and Sombrock, W.G. (1991). World map of the status of human-induced soil degradation. An explanatory note 2nd revised edn. International Soil Reference and Information Center. Wageningen.

Olsen, R.S., and Sommer, L.E., (1982). Phosphorus in: methods of soil Analysis part 2 (ed Page, A.L, Miller,R.H and Keeney, D.R). American Soc. Of Agronomy Madison, Wisconsin pp 15-72.

Onweremadu, E.U., and Oti, N.N. (2005). Soil colour as indicators of soil quality in soils formed over coastal plain sands of Owerri agricultural area, South-eastern Nigeria. Int. J. of Natural and Applied Sciences 1(2):118-121.

Onweremadu, E.U. (2006). Assessment of mined soils in erosion-degraded farmlands in Southeastern Nigeria. Estud. Boil., 28(65)59-67.

Onweremadu, E.U. (2007a). Pedology of Near Gully Sites and its implication on the Erodibility of Soils in Central Southeastern Nigeria. Research Journal of Environmental Sciences 1(2): 71 – 76.

Onweremadu E.U, (2007b). Soil carbon distribution in a hilly landscape. International Journal of Agricultural Research 2(4) 377-384.

Onweremadu, E.U, Eshett, E.T., Osuji, G.E., Unamba-Opara, I., Obiefuna, J.C., Onwuliri, C.O.E., (2007a). Anisotropy of edaphic properties in slope soils of a university farm in Owerri, southeastern Nigeria. Journal of American science, 3(4): 52-62.

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

Onweremadu, E.U, Osuji, G.E., Eshett, E.T., Opara, C.C and Ibeawuchi, I.I. (2007c). Characterization of soil properties of owner managed farms of Abia and Imo States for sustainable crop production in South-east Nigeria. Journal of American Science. 3(1) 28-37.

Onweremadu, E.U., Mathews-Njoku, E.C., Nnadi, F.C., Anaeto, Ugwuoke, F.O., Onu, D.O and Odii, M.A.C.A (2008a). Deterioration of soil organic components and adoptability of green fallows for soil fertility replenishment. J of Am. Sc 4(2). ISSN 1545-1003. http://www.american Science.Org.

Onweremadu, E.U., Onyia, V.N and Anikwe, M.A.N. (2008b). Geospatial distribution of soil organic matter in soils of Imo and Abia areas, southeastern Nigeria. Journal of Environmental Research and Policies 3(1) 46-53.

Onweremadu, E.U., F.O.R. Akamigbo and C.A. Igwe (2008c). Soil quality morphological index in relation to organic carbon content of soils of Southeastern Nigeria. Trends in Applied Science Research 3(1): 76-82.

Onweremadu, E.U., Okon, M.A., Ihem, E.E., Okuwa, J., Udoh, T.B., and Imadojemu, P (2011). Soil exchangeable calcium mapping in central south-eastern Nigeria using Geographic Information Systems. Nigerian Journal of Agriculture, Food and Environment 7(2): 24-29.

Onyeagocha, A.C. (1980). Petrography and depositional environment of the Benin formation. Journal of Mining and Geology 17, 147 – 152.

Orajaka, S. O. (1975). Geology. *In*: G.E.K. Ofomata (ed.) Nigeria in maps: Eastern states. Benin City: Ethiope Publishing House. Pp. 5-7.

Oriowo, T.I. (1989). Soil characteristics and root distribution pattern in a regrowth forest B.SC Thesis. Obatemi Awolowo University Ile-Ife Nigeria.

Ortega, R.A, Peterson, G.A, Westfall, D.G. (2002). Residue accumulation and changes in soil organic matter as affected cropping intensity in no-till dry land agro-ecosystems. Agron. J. 94:944 – 945.

Osuji, G.E., Eshett, E.T., Oti, N.N. and Ibeawuchi, I.I. (2002) Land use practices and the predisposition of selected watersheds in Imo State to erosion. In: *Proceedings of the 36th Annual Conference of the Agricultural Society of Nigeria* held at Federal University of Technology, Owerri, Nigeria. Pp. 397-401.

Oti, N.N, (2007). Assessment of fallow as a natural strategy to restore erosion-degraded lands. International Journal of Agric. and Rural Development 9: 22-29

Ozor, N. (2009). Implications of climate change for National Development: The way forward. In: Enugu Forum Policy Paper 10. (AIAE) Eds. Eboh *et al.*

Palm, C.A, Gachengo, C.N, Delve, R.S., Cadisch, G., and Giller, K.E. (2001). Organic inputs for soil fertility management in tropical agro-ecosystems. Application of an organic resource database. Agriculture and environment 83: 27-42.

Parson, E.A., Haas, P.M., and Levy, M.A. (1992). A summary of the major documents signed at the Earth Summit and the Global Forum. Environment 34: 12-15.

Parton, W.J., Schimel, D.S., Cole, C.V and Ojima, D.S. (1987). Analysis of factors controlling soil organic matter levels in great plains grasslands. Soil Science Society of American Journal. 51. 1173-1179.

Patino-zuniga, L., Ceja-Navaro. J.A., Govaerts, B., Luna-Gudo, M., Sayre, K.D., and Dendooven, L. (2008). The effect of different tillage and residue management practices on soil characteristics, inorganic nitrogen dynamics and emissions of N_2O, CO_2, and CH_4 in the central highlands of mexico: A laboratory study. Plant Soil DO1 10.1007/S1104-008-9722-1.

Payne, R. W.; Murray, D. A.; Hardings, S. A.; Baird, D. B. and Soutar, D. M. (2007). GenStat for windows (12th Edition). VSN International Ltd, Hemel Hempstead.

Pena-Mendez, E.M., Josef Havel and Givi Patocka, (2005). Humic substance-compounds of still unknown structure: Applications in agriculture, industry, environment and biomedicine. Journal of applied biomedicine. 3:13-24.

Percy, K.E. J and l, R., Hall, J.P., and Lavignc, M. (2003). The role of forests in carbon cycles, sequestration and storage. Newsletter No.1 5pp.

Pettit, (2012). Organic matter. Humus, humate, humic acids, fulvic acid and humin. Texas A&M university.

Poach, M.E and Faulkner, S.P. (1998). Phosphorus characteristics of created and natural wetlands in the Atchafalaya Delta, Louisiana. Estuar. Coastal Shelf Science. 46: 195-203.

Potter, K.N, Jones, O.R, Torbest, H.A, Unger, P.W (1997). Crop rotation and tillage effected on organic carbon sequestration in the semi-arid southern great plains. Soil sci. 152:140 – 147.

Potter, K.N, H.A. Torbert, H.B. Johnson and C.R. Tischter, (1999). Carbon storage after long-term grass establishment on degraded soils. Soil Science 164: 718-725.

Post, W., and Kwon, K (2000). Soil carbon sequestration and land use change: processes and potential. Global Change Biology. 6, 317-328.

Poulton, P.R. (1995). The importance of long term trials in understanding sustainable farming systems. The rothamsted experience. Australian Journal of Experimental Agric. 35: 825-834.

Poulton, P.R., Pye, E., Hargreaves, P.R. and Jenkinson, D.S. (2003). Accumulation of carbon and nitrogen by old arable land reverting to woodland. Global Change Biology, 9, 942-955.

Power, J.F., (2007). Legumes: Their potential role in agricultural production. Organic farming. Pp 5.

Powlson, D.S. & Jenkinson, D.S. (1981). A comparison of the organic matter, biomass, adenosine triphosphate and mimeralizable nitrogen contents of ploughed and direct drilled soils. *Journal of Agricultural Science, Cambridge,* **97,** 713 – 721.

Powlson D.S, A.P. Whitemore and W.T. Goulding (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. European Journal of Soil Science 62: 42-55.

Pretty, J and Ball, A. (2001). Agricultural influences on carbon emissions and sequestrations: A review of evidence and the emerging trading options. University of Essex, Center for Environment and Society, Occasional paper 2001-03.

Prior, S.A., Runion, G.B, Torbert, H.A. Rogers, H.H., and Reeves, D.W. (2003). Effects of elevated atmospheric CO_2 on biomass production and carbon sequestration: conventional and conservation cropping systems. In: Proc. 6th ISTRO Conference, pp. 943-948. 13-18 July, Brisbane Australia.

Puget, P., Chenu, C., and Balesdent, J. (2000). Dynamics of soil organic matter associated with particle –size fraction of water-stable aggregates. European Journal of Soil Science. 51, 595-605.

Raji, B.A and Ogunwole, J.O. (2006). Potential of soil carbon sequestration under various land use in the sub-humid and semi arid savanna of Nigeria: lessons from long term experiments. International Journal of Soil Science, 1: 33-43.

Raji, B.A. (2011). Predicting the CEC of soils of the Nigerian savanna. Nigeria Journal of Soil Science 21(1): 22-33

Raji, B.A. and Obidike, E.O. (2011). The effects of fallow on soil carbon storage after long term continuous application of inorganic and organic fertilizers in a sub-humid savanna Alfisols. Nigeria Journal of Soil Science 21(1):34-40

Reid, G. and Dirou, J. (2004). How to Interpret your soil Test. [Online] Available: http://www.dpi.nsw.gov.au/agriculture/resources/soils/testing/interpret.

Reyment, R.A. (1965). Review of Nigeria Cretaceous Strata. Journal of Mining Geology 2(2) 61-80

Rezaei, S.A., and Gilkes, R.J. (2005). The effects of land scape attributes and plant community on soil chemical properties in rangelands. Geoderma 125: 167-176.

Rice, C.W. (2002). Organic matter and nutrient dynamics. In: Encyclopedia of soil science. Pp 925-928. New York, USA, Marcel Dekker Inc.

Robbins, M. (2004). Carbon trading, agriculture and poverty. World Association of Soil and Water Conservation (WASWC). Special publication No. 2. Beijiing, China.

Robert Jandl, Lindner, M., Vesterdal, L., Bauwens, B., Baritz, R., Hagedom, F. (2007). How strongly can forest management influence soil C sequestration?
Geoderma 137: 253-268.

Robertson, G.P, Huston, M.A., Evans, F.C andTiedje, M.J. (2000). Green house gases in intensive agriculture : Contributions of
individual gases to the radiative forcing of atmosphere. Science Magazine 289(5486): 1922-1925.

Roth, C.H. (1985). Infiltrabilitat von Latosolo-Roxo-Boden in Nordparana, Brasilien, in Feldversuchen zur Erosionskontrolle mit verschiedenen Bodenbearbeitungs-systemen und Rotationen. Got. Bod. Ber., 83: 1-104.

Ruthenberg, H., (1980). Farming system in the tropics, 3rd ed., Clarendon Press, Oxford UK.

Salako, F and Tian, G., (2001). Litter and biomass production from planted and natural fallows on a degraded soil in Southwestern Nigeria, agro-forestry System. 51, 239-251

San Jose, J.J., and Montes, R.A., (2001). Management effects on carbon stocks and fluxes across the Orinoco Savannas. Forest Ecology Management 150: 293-311.

Sanchez, P.A. (1976). Properties and management of soils in the tropics. New York: John Wiley and Sons. 618 pp.

Sanchez, P.A. Soil fertility and hunger in Africa. (2002). Science 295 (5562): 2019-2020

Sarmiento, L and Bottner, P. (2002). Carbon and nitrogen dynamics in two soils with different fallow times in the high tropical Andes: Indications for fertility restoration. Applied Soil Ecology. 19:79-89.

Schimel, D.S., Coleman, D.C., and Horton, K.A (1985). Soil organic matter dynamics in paired ranged and crop toposequence in North Dakota. Geoderma. 36: 201-214.

Schimel, D.S., Enting, I.G., Heimann, Wigley, T.M., Raynaud, D., Alves, D and Schnitzer, M. (1986). The synthesis, chemical structure, reactions and functions of humic substances. In: R.G. Burns, G. Dell'Agnola, S. Miele, S. Nardi, G. Savoini, M. Schnitzer, P. Sequi, D. Vaughan and S.A. Visser, eds. Humic substances: effect on soil and plants. Congress on humic substances. Millan, Italy.

Schjonning, P., chemistensen, B.T and Carstensen, B. (1994). Physical and chemical properties of a sandy loam receiving animal manure, mineral fertilizer or no fertilizer or no fertilizer for 90 years. European Journal of Soil science, 45, 257-268

Schlesinger W.H.(1990). Evidence from chronosequence studies for a low carborn – storage potential of soils. Nature 348:232 – 234.

Schlesinger W.H.(1999). Carbon sequestration in soils. Nature. 284: 2095 -2096

Schlesinger W.H. and Lichter, J. (2001). Limited carbon storage in soils and litter of experimental forest plots under increased atmospheric carbon dioxide. Nature. 411: 466-469

Schnitzer M. (1982). Total carbon, organic matter and carbon in methods of soil analysis-part 2, Agronomy monograph, A.I. Page\, R.H Miller, & D.R keeney, Eds. American society of Agronomy. Madison, WIS, USA 2nd edition. Vol.9 PP 539 – 577

Scott, B.J., and Conyers, M.K. (1995). Magnesium nutrition and lime movement down the profile. Making better fertilizer and gypsum recommendation, a workshop in Wagga Wagga eds. Fenton, G and Orchard, P. NSW. Agriculture

Shrestha, R.K and Lal, R. (2011). Changes in physical and chemical properties of soil after surface mining and reclamation. Geoderma. 161: 168 – 176.

Schroth, G., Sammya, A.D.A., Teixeira, W.G., Haag, D., and Lieberei, R. (2002). Conversion of secondary forest into agro-forestry and monoculture plantation in Amazonia, consequences for biomass, litter and soil carbon stocks after 7 years. Forest ecology and management, 163, 131-150.

Schulze, D. G., Nagel, L. L., van Scoyoc, G. E., Henderson, T. L., Baumgardner, M. F., and Stott, D. E. (1993). Significance of organic matter in determining soil color. In 'Soil color. Vol. SSSA Special Publication number 31.' (Eds J. M. Bigham and E. J. Ciolkosz.) pp. 71-90. (Soil Science Society of America: Madison, WI.)

Senjobi, B.A., (2007). Comparative assessment of the effect of land use and land type on soil degradation and productivity in Ogun State, Nigeria. Published ph.D. thesis submitted to the Department of Agronomy, University of Ibadan, Ibadan. Pp161.

Senjobi, B.A., and Ogunkunle, O.A. (2010). Effect of Land use on soil degradation and soil productivity decline on Alfisols and Ultisols in Ogun State in Southwestern Nigeria. J. Agric. Conspectus Sci. Faculty of Agric, University of Zagreb Croatia 75(1): 9-19.

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

Shaw, G., and Wheeler, D. (1996). Statistical techniques in geographical analysis. David Fulton Publishers. London.

Shi, W. and J.M. Norton. 2000. Microbial control of nitrate concentrations in an agricultural soil treated with dairy waste compost or ammonium fertilizer. Soil Biol. Biochem., 32:1433-1457

Shrewoods, S., and Uphoff, N. (2000). Soil health. Research, practice and policy for a more regenerative agriculture. Applied Soil Ecology 15: 85- 95.

Siegenthaler, U. (1994). CO2 and the carbon cycle. In: J.T. Houghton *et al* (ed). Climate change. Cambridge University Press, New York Pp 35-71.

Singh, S., and Singh, J.S. (1996). Water stable aggregates and associated organic matter in forest savannah and cropland soils of seasonally dry tropical region. Indian Biology and Fertility of Soil. 22: 76-82.

Sisti, C.P.J., Dos Santos, H.P., Kohhann, R., Alves, B.J.R., Urquiaga, s., and Boddey, R.M. (2004). Change in carbon and nitrogen stocks in soil under 13 years of conservational or zero tillage in southern brazil. Soil and Tillage Research 76: 39-58.

Six, J., Callewaert, P., Leuders, S., Gryze, S.D., Morris, S.J., Gregorich, E.G., Paul, E.A., and Paustian K (2002). Measuring and understanding carbon storage in afforested soils by physical fractionation. Soil Science Society of America, J. 66, 1981-1987.

Six, J., Ogle, S.M., Breidt, F.J., Conant, R.T., Mosier, A.R., Paustian, K. (2004). The potential to mitigate global warming with no-tillage management is only realized when practice in the long-term. Global Change Biology 10: 155-160.

Skjemstad, J.O., Lefeuvre, R.P and Prebble, R.E. (1990). Turnover of soil organic matter under pasture determined by C natural abundance. Australian Journal of Soil Research, 28, 267-276.

Skjemstad, J. O. (2000). Agric management practices. In: workshop proc. Management options for carbon sequestration in forest, Agric and rangeland ecosystems; CRC for greenhouse accounting. 25 May 2000. Pp 54.

Skjemstad, J.O., Dala, R.C., Janik, L.J and MCGowan, J.A. (2001). Changes in chemical nature of soil organic carbon in vertisols under wheat in south-eastern Queensland. Australian Journal of Soil Research. 39: 343-349.

Smith, K.A., Ball, T., Conen, F., Dobbie, K.E., Massheder, J., and Rey, A. (2003). Exchange of green house gasses between soil and atmosphere intaractions of soil physical factors and biological processes. European Journal of Soil Science 54:779-791

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

Sobulo, R.A. (1973) Evaluation of analytical methods for determining the potassium status of Nigerian soils. *In: Proceedings of the 10 Colloquium of the International Potash Institute* held at Abidjan, Cote d'Ivoire. Pp. 87.

Soil Survey Staff (1975). Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agricultural Handbook No 436, Washington DC. 754 pp

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

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

Soil Survey Staff (2010). Keys to Soil Taxonomy, Eleventh Ed. USDA, Washington D.C. 869PP

Sombroek, W.G. (1990). Geographic quantification of soil and changes in their properties. In : Soil and green house effect. Pp. 225 -244. (ed. A.F. Bouwman) John Wiley and sons, Chichester.

Somboek, w.g., nachtergaele, F.O., and Hebel, A. (1993). Amount, dynamic and sequestrations of carbon in tropical and sub-tropical soils. Ambio, 22, 417 - 426.

Spaccini, R., A. Piccolo, J.S.C. Mbagwu, A., Zena-Teshale and C.A. Igwe, (2002). Influence of the addition of organic residues on carbohydrate content and structural stability of some highland soils in Ethiopia. Soil Use Manage., 18:404-411.

Spain, A.V., Isbell, R.F and Probert, M.E. (1983). Soil organic matter. In: soils: An Australia view point; CSIRO. Mellbourne. Academic press. London pp 551-563.

SPSS (2009). SPSS Statistics for windows. Version 17.0 SPSS Inc., Chicago USA.

Steffens, M., Kolbl, A., Totsche, K.U. and Kogel-Knabner,I. (2008). Grazing effects on soil chemical and physical properties in a semiarid steppe of inner Mongolia (P.R. China). Geoderma 143:63-72.

Stevenson F.J. (1982). Humus chemistry genesis, composition, reactions. Willey Inter-science. New York.

Stevenson, F.J. (1994). Humus chemistry. Genesis, composition, reactions. 2nd edition. New York, USA, Willey Inter-science. 512pp.

Stirling, M. (2001). Soil biology and its important in soil health. In: soil health. The foundation o f sustainable agric; proc of a workshop on the importance of soil health in agric, Ed. R. lines-kelly, Wollong-bar Agricultural Institute, NSW, pp 24-29.

Styger, E. *et al* (1999). Indigenous fruit trees of Madagascar : Potential components of agro-forestry system to improve human nutrition and restore biological diversity. Agro-forestry system: 46, 289-310

Styger, E. Fernandes, and Erick, C.M., (2006). Contributions of managed fallows to soil fertility recovery. In: uphoff, N. B., A.S., Fernandes, E. Herren, H. Husson, O. Laing, M., Palm, C., Pretty, J., Sanchez, P.A., Sanginga, N., Thies, J.E (eds.). biological approaches to sustainable soil systems. CRC Press. Taylor and Francis group, Boca Raton, FL. Pp 425-437.

Swift R.S (2001). Soil organic carbon – potential for sequestration and recycling. Workshop on recycled organics –partnership, processes and products 25-27 September, 2001. University of Queensland, Galten, pp 21-27.

Tan, K.H and Binger, A. (1986). Effect of humic acid on aluminum toxicity in corn plants. Soil Sci., 14: 20-25.

Tan, K.H. (1994). Environmental soil science. New York, USA, Marcel Dekker Inc. 304pp.

Tan, K.H. (2003). Chemical composition of humic matter. In: humic matter in soil and environment. Principles and controversies. Marcel and Dekker New York.

Tate, R.L., (1987). Soil organic matter: biological and ecological effects. New York, USA, John Wiley and Sons. 291 pp.

Terra, J.A., Shaw, J.N., Reeves, D.W., Raper, R.L., Van Santen, E., Mask. P.L. (2004). Soil carbon relationships with terrain attributes, electrical conductivity, and a soil survey in a coastal plain landscape. Soil Science. 169: 819 – 831.

Theng, B.K.G. (1987). Clay-humic interactions and soil aggregate stability. In P. Rengasamy, ed. Soil structure and aggregate stability. Pp. 32-73. Proc. Institute of Irrigation and Salinity Research. Tatura, Australia.

Tian,G., Salako, F.K., Ishida, F. (2001). Replenishment of C, N and P in a degraded Alfisol under humid tropical conditions: effect of fallow species and litter polyphenols. Soil Science, 166:614-621.

Tijani, M.N., Nton, M.E and Kitagawa, R. (2010). Textural and geochemical characteristics of the Ajali Sandstone, Anambra Basin, Sout-eastern Nigeria. Implication for its provenance. Geosciences, 342 136 -150

Tisdall, J.M., and Oades, J.M.(1982). Organic matter – stable aggregates in soils. Journal of Soil Science 33: 141- 163.

Tisdale, S., Nelson, W.L., Beaton, J.D. (1985). Soil fertility and fertilizers. New York Macmilian Publ. company. 754pp.

Thomas, G.W., (1996). Soil pH and Soil Acidity. In: Methods of soil analysis, part 3- chemical methods. L.D. Sparks (ed). SSSA Book Series. No 5.

Thomas, R.G. and Asakawa, N.M. (1993). Decomposition of leaf litter from tropical forage grasses and legumes. Soil Biology and Biochemistry, 25(10) 1351-1361.

Trabalka, J.R and Reichle, D.E (1986). The changing carbon cycle; a global analysis. Springer-verlag, New York.

Turner, J and Lambert, M. (2000). Change in organic carbon in forest plantation soils in eastern Australia. Forest Ecology and Management, 133:231-247.

United Nations frame Work Convention on climate change (UNFCC) (1992). United Nations Frame Work Convention on Climate Change; available at www.unfccc.de/resource/convention/index.html.

United Nation on Climate Change Reference (UNCCR) (2007).

United Nations frame Work Convention on climate change (UNFCC)(2002). Report of the conference of the parties on its 7th session, held at Marrakesh.

United Nation Land Degradation (UNLD) (2007). Land Use Cover Data Sources Ref. 22pp.

United States Department of Agriculture (USDA) (2001). RPA Assessment of forest and range lands. Forest Service Report No. FS-687. Forest Service, Washington DC. 78pp.

United States Department of Agriculture (USDA), (2003). Keys to soil taxonomy. Pp 331

United States Department of Energy (USDE), (2010). Climate change solution and carbon sequestration

United State Geological Survey (USGS) (2011). National oil and gas assessment. U.S Geological Survey

Uzoho, B.U, Ekpe, I,I., Ahukaemere, C.M., Ndukwu, B.N., Okoli, N.H., Osisi, FA., Chris-Emenyonu, C.M. (2014). Nitrogen status of soils of selected land-uses of two cropping systems in the humid tropical rainforest, southeastern Nigeria. Advances in Life Science and Technology. 25:24-33

Vandawater, H., and Valetin, C., (1992). Soil crusting. The African view. In: soil crusting. Chemical and physical process. B.A., Stewart (ed.). Lewis publisher.

Van Duivenbooden, N., Windmeijer, P.N, Anderiesse, W and Fresco, L.O. (1996). The integrated transect method as a tool for land use characterization with special reference to inland valley agro-ecosystem in most Africa landscape and urban planning, 34: 143-160.

Van Minnen, G.J. (2008). The terrestrial carbon cycle on the regional and global scale. Modeling, uncertainties and policy relevant doctorial thesis. Wageningen Univ. 221pp.

Van Wambeke, A.R. (1962). Criteria for classifying tropical soils by age. Journal of Soil Science. 13: 124-132

Vermeer, A.W.P. (1996). Interactions between humic acid and hematite and their effects on metal ion speciation . Wageningen University, the Netherlands. (PhD thesis). 215pp.

Veres (2002). A Comparative Study Between Loss on Ignition and Total Carbon Analysis on Minerogenic Sediments. Studia Universitasis Babes-Bolyai, Geologia, XLVII, 1, 2002, 171-182

Violante, A. and Violante, P. (1980). Influence of pH, concentration and chelating power of organic anions on the synthesis of aluminum hydroxide and oxy-hydroxides: clays and clay minerals 28, 425-434.

Vine, H. (1954) Latsoils of Nigeria and some related soils. Proceedings of 2nd Inter African Soils Conference

Violante, A., and Huange P.M., (1985). Influence of inorganic and organic ligands on the formation of aluminum hydroxides and oxyhydroxides: Clays and clay minerals, 33,181-192.

Wakene N. (2001). Assessment of important physiochemical properties of Nitosols and different management systems in Bako Area, Western Ethiopia. MSc thesis, Alemaya, Ethiopia.

Walker, S.M and Desanker, P.V. (2004). The impact of land use on soil carbon in Micmbo Woodlands of Malawi. Forest Ecology and Management, 203: 345-360.

Wang, J., Fu, B., Yang, Q., and Chen, L. (2001). Soil nutrient in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China. Journal of Arid environment., 48:537-550.

Wang, Z.M., Zhang, B., Song, K.S., Liu, D.W., Li, F., Guo, Z.X., and Zhang, S.M. (2008). Soil organic carbon under different landscape attributes in croplands of north east china. Plant Soil Environ. 54: 420-427.

Weibe, Keith (2003). Linking land quality, agricultural productivity, and food security. Agricultural Economic Report No. (AER823). Pp 63

Wilding, L.P and Hossner, L.R., (1989). Cause and effects of acidity on soils. IITA-Ibadan, Nigeria and Institute of Soil Fertility, Harem, the Netherlands, Pp 39-59.

Wilding, L.P., J. Bouma, and D.W.Boss. (1994). Impact of special variability on interperative modeling. In: Bryant, R.B and R.W. Amold. Quantitative modeling of soil forming process. SSSA special publ., No. 39: 6175

Wilding, L. P. 1985. Spatial variability: Its documentation, accommodation, and implication to soil surveys. In: Soil spatial Variability. Nielsen, D. R., Bouma, J. (Eds). Pudoc. Wageningen, The Netherlands, pp. 166-194.

William, R.J. (2008). Humic, fulvic and microbial balance: organic soil conditioning. A complete book overview. 935pp.

Wilson, G.F and Caveness, F.E., (1980). The effects of rotational crops on the survival of root knots, root lesions and spiral nematodes. Nematropica 10: 56-61.

Woodward, F.I., Bardgett, R.D., Raven, J.A. & Hetherington, A.M. (2009) Biological approaches to global environmental change mitigation and remediation. Current Biology, 19, R615-R623.

Woomer, P.L and Muchena, F.N. (1993). Overcoming soil constrains in crop production in tropical Africa. In: Ahenkorah, Y., Owusu-Bennoah, E., Dowuona, G.N.N (eds.). Sustaining soil productivity in intensive African agriculture. Seminar Proc. Of the Technical Center for Agriculture and Rural Co-operations ACP-EU, Accra Ghana 15-19 Nov. pp 45-56.

World Bank (2011). Nigeria Crop Weather Index Insurance, Pre-feasibility Study Report. Pp 139.

World Reference Base for Soil Resources (2006). A framework for international classification, correlation and communication. World soil resources reports 103. Pp 128.

Wu, J. (2011). Carbon accumulation in paddy ecosystems in subtropical China: evidence from landscape studies. European Journal of Soil Science. 62, 29-34.

Yano, Y, Mcdowell, W.H., and Aber, J.D., (2000). Biodegradable dissolved organic carbon in forest soil solution and effects of chronic nitrogen deposition. Soil Biology and Biochemistry, 32:1743-1751

Yemefack, M., Nounamo, L., Njomgang, R and Bilong, P. (2002). Effects of natural fallow on topsoil properties and subsequent crop yields in a forest Oxisols of southern Cameroon. Symposium. 17th WCSS, 14 -21 August, Thailand.

Yihenew, G.S. and Getachew A (2013). Effects of different land use systems on selected physicochemical properties of soils in Northwestern Ethiopia. 5 (4) 112-120.

Yimer, F., Ledian, S and Abdelkachi, A. (2008). Concentration of exchangeable bases and cation exchange capacity in soils of cropland, grazing and forest in Bale Mountains, Ethiopia. Forest Ecology and management, (256):6, 1298 – 1302.

Zhang C.S, and Mc Grabh, D.C (2004). Geo-statistical and GIS analyses on soil organic carbon concentrations in grassland of southeastern Ireland from two different periods. Geoderma. 119: 261-275.

Zibilske, L.M., and Brandford, J.M. (2007). Soil aggregation, aggregate carbon and nitrogen, and moisture retention induced by conservation tillage. Soil Science Society of American J. 71:793-802

Zinati, G.M., Li, Y.C. and Bryan, H.H (2001). Utilization of compost increases organic carbon and its humin, humic and fulvic acid fractions in calcareous soil. Compost Science and Utilization 9: 156-162.

Appendix 1: Profile distribution of Physico-chemical properties of soils derived from different parent materials

Profile distribution of Physical properties of cultivated soils derived from Falsebedded sand stones

DEPTH Cm	HOR	sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	SCR	BD gcm^{-3}	MC %	TP %	WSA %	MWD Mm
	Profile1									
0-9	AP	804	128	68	1.88	1.01	6.48	61.89	15.15	0.60
9—26	AB	744	188	68	1.29	1.12	7.05	57.74	12.80	0.57
26-80	Bt1	724	208	68	3.06	1.21	20.89	54.34	10.92	0.44
80-103	Bt2	784	148	88	1.68	1.21	9.97	46.04	12.29	0.34
103-180	Bt3	764	168	68	2.47	1.43	12.8	35.47	8.08	0.44
	CV(%)	4.4 0	19.0	12.0	34.0	13.3	51.0	99.12	22.1	23.0
	Profile2									
0-9	AP	764	168	68	2.47	0.9	15.33	66.04	14.1	0.44
9---29	AB	764	168	68	2.47	1.06	7.14	60.00	14.02	0.46
29-50	Bt1	764	168	68	2.47	1.20	6.45	54.72	10.86	0.43
50-79	Bt2	764	148	88	1.68	1.21	8.52	54.60	17.63	0.31
79-120	Bt3	724	208	68	3.05	1.36	9.00	48.68	3.482	0.30
120-180	Bt4	724	208	68	3.05	1.48	10.6	38.88	12.04	0.59
	CV(%)	2.75	14	11	20	17	34	17	38	26
	Profile3									
0-17	AP	824	108	68	1.59	1.12	8.20	57.74	10.81	0.56
17-29	AB	804	128	68	1.88	1.30	9.61	50.94	11.38	0.40
29-46	Bt1	844	68	88	0.77	1.15	9.07	56.60	13.18	0.27
46-98	Bt2	764	168	68	2.47	1.58	15.22	32.83	15.91	0.64
98-178	Bt3	744	168	88	1.91	1.58	14.83	32.83	13.09	0.63
	CV (%)	5.2	33.15	14.41	36.03	16.66	29.5	26.98	15.46	31.75

SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation, (Wilding, 1985)

Profile distribution of Physical properties of forest soils derived from Falsebedded sand stones

DEPTH	HOR	Sand	Silt	Clay	SCR	BD	MC	TP	WSA	MWD
Cm		gkg^{-1}	gkg^{-1}	gkg^{-1}		gcm^{-3}	%	%	%	Mm
		Profile 4								
0-1	Oe	764	188	48	3.91	0.71	5.51	73.21	36.12	1.99
1-3	Oa	764	188	48	3.91	1.01	6.74	61.89	39.36	2.14
3-9	A	784	188	28	6.71	1.01	8	61.89	25.67	1.23
9-40	AB	744	208	48	4.33	1.24	18.06	53.21	21.02	0.97
40-89	Bt1	764	168	68	2.47	1.37	9.32	48.3	22.86	0.72
89-160	Bt2	744	178	78	2.28	1.42	10.59	46.42	18.96	1.35
	CV(%)	1.98	7.13	33.22	40.57	23.78	46.09	17.59	30.82	40.13
		Profile 5								
0-2	Oe	824	128	48	2.67	0.81	4.98	69.43	23.52	0.88
2—4	Oa	824	128	48	2.67	0.82	8.82	69.06	21.23	0.59
4—13	A	724	108	128	0.84	1.06	8.98	60	23.8	0.51
13-49	AB	744	138	98	1.41	1.26	10.95	52.45	15.86	0.57
49-91	Bt1	784	108	108	1	1.35	10.97	49.06	15.3	1.06
91-158	Bt2	724	138	180	0.77	1.37	14.55	48.3	15.44	1.10
	CV(%)	6.07	10.96	50	57	22.91	32.05	16.55	21.42	33.43
		Profile 6								
0—3	Oa	804	108	88	1.23	0.82	5.6	69.06	26.57	2.19
3—15	A	764	108	128	0.84	0.96	13.2	60.75	25.69	1.99
15-60	AB	724	128	148	0.87	1.2	12.5	54.72	24.33	1.77
60-131	Bt1	724	128	148	0.87	1.35	10.61	49.06	15.24	1.53
	CV(%)	5.08	9.79	22.09	19.48	21.94	32.75	14.66	22.77	15.24

Oe = Hemic horizon, Oa = Sapric, SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Physical properties of fallow soils derived from Falsebedded sand stones

DEPTH Cm	HOR	sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	SCR	BD gcm^{-3}	MC %	TP %	WSA %	MWD Mm
			Profile 7							
0-18	A	804	128	68	1.88	0.90	6.65	66.04	20.03	0.91
18—49	AB	824	108	68	1.59	1.00	6.78	62.26	19.83	0.88
49-98	Bt1	764	168	68	2.47	1.11	6.87	58.12	16.98	0.68
98-145	Bt2	764	148	88	1.68	1.37	10.53	48.30	13.659	0.56
	CV (%)	38	18.71	13.69	20.77	18.48	24.44	13.02	16.96	21.87
			Profile 8							
0-9	A	824	128	48	2.66	0.90	7.45	66.04	17.09	0.79
9—35	AB	724	118	138	0.85	1.18	8.67	55.47	18.38	1.00
35-76	Bt1	764	128	108	1.19	1.24	8.09	53.21	20.81	1.20
76-140	Bt2	704	138	158	0.87	1.35	10.58	49.06	21.12	1.00
	CV (%)	7.02	6.37	42.44	64.29	16.42	15.52	12.93	10.00	16.87
			Profile 9							
0-15	A	844	78	78	1.00	1.21	11.06	54.34	16.214	0.76
15-33	AB	744	178	78	2.28	1.25	12.08	52.83	15.249	0.45
33-98	Bt1	724	188	88	2.14	1.35	13.10	49.06	19.23	0.63
98-130	Bt2	744	188	68	2.77	1.41	18.22	46.79	18.54	0.50
	CV(%)	7.09	33.89	10.47	36.57	7.01	23.36	6.80	10.89	23.85

SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter,Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Table 4 : Profile distribution of Physical properties of forest soils derived from Shale

DEPTH Cm	HOR	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	SCR	BD gcm^{-3}	MC %	TP %	WSA %	MWD Mm
			Profile10							
0-5	Oa	704	88	108	0.82	0.87	5.76	67.17	40.11	2.71
5—19	A	534	248	218	1.14	0.97	8.34	62.36	34.22	1.95
19-56	AB	604	168	328	0.51	1.26	11.00	52.45	31.62	1.60
56-98	Bt1	264	388	348	1.12	1.27	10.48	52.08	38.95	2.65
98-142	Bt2	204	388	408	0.95	1.34	14.54	49.40	27.26	0.98
142-189	Bt3	204	348	448	0.78	1.34	15.30	49.40	30.24	1.48
	CV(%)	52.84	46.01	40.77	26.69	17.26	33.30	13.46	14.92	36.16
			Profile 11							
0—3	Oa	604	188	208	0.9	0.82	10.02	69.06	49.70	2.55
3—10	A	604	168	228	0.74	1.06	13.03	60.00	58.01	2.11
10—36	AB	364	288	348	0.83	1.25	11.99	52.45	57.86	2.91
36-60	Bt1	204	348	448	0.78	1.29	13.34	51.29	28.97	0.85
60-110	Bt2	104	408	488	0.84	1.33	16.99	49.80	25.64	1.89
110-185	Bt3	264	208	528	0.33	1.36	17.93	48.83	28.01	1.78
	CV(%)	58.45	33.45	36.15	28.04	17.53	21.75	14.20	37.41	35.33
			Profile 12							
0—3	Oa	604	148	248	0.60	0.81	8.79	69.43	36.39	1.95
3—14	A	464	248	288	0.86	0.96	8.82	63.77	27.15	1.55
14-50	AB	304	368	328	1.12	1.29	10.75	51.29	37.34	1.31
50-89	Bt1	284	348	368	0.95	1.38	7.90	47.95	39.23	1.10
89-127	Bt2	164	368	468	0.79	1.37	15.20	48.30	38.11	2.19
127-189	Bt3	164	268	568	0.47	1.38	14.10	47.95	39.12	1.40
	CV(%)	53.5	29.9	31.70	29.51	20.83	27.91	17.17	12.63	25.92

Oa = Sapric, horizon, SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Physical properties of cultivated soils derived from Shale

DEPTH Cm	HOR	Sand gkg^{-1}	silt gkg^{-1}	Clay gkg^{-1}	SCR	BD gcm^{-3}	MC %	TP %	WSA %	MWD Mm
	Profile13									
0-12	AP	704	148	148	1.00	1.24	16.58	54.72	21.47	0.84
12—66	AB	304	308	388	0.79	1.28	12.91	51.70	14.44	0.42
66-104	Bt1	584	168	248	0.68	1.35	17.06	49.06	32.90	1.01
104-143	Bt2	204	208	588	0.35	1.35	13.81	49.06	11.65	0.61
143-180	Bt3	204	248	558	0.43	1.37	15.68	48.30	15.60	0.91
	CV (%)	57.59	38.84	49.44	40.81	4.20	1.18	5.25	43.95	31.59
		Profile14								
0-9	AP	664	148	188	0.79	1.31	11.88	50.57	18.61	0.52
9-70	AB	564	188	248	0.79	1.31	14.71	50.57	10.92	0.76
70-89	Bt1	204	408	388	1.05	1.35	16.41	49.06	18.37	0.98
89-117	Bt2	264	208	528	0.39	1.42	18.49	46.41	14.48	0.45
117-180	Bt3	164	208	628	0.33	1.47	17.04	44.53	19.05	1.67
	CV (%)	60.89	43.70	46.65	45.22	5.16	16.13	5.55	21.59	56.56
		Profile15								
0-9	AP	664	148	188	0.78	1.22	13.09	53.96	20.32	1.00
9-68	AB	664	88	248	0.36	1.26	14.08	52.45	16.93	0.65
68-105	Bt1	304	288	408	0.71	1.26	16.44	52.45	16.77	0.93
105-133	Bt2	304	248	448	0.55	1.41	14.22	46.79	15.00	0.98
133-185	Bt3	164	248	668	0.37	1.42	16.37	46.41	18.97	1.23
	CV (%)	54.8	40.66	48.05	34.59	7.13	10.07	7.02	11.77	21.52

SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Physical properties of fallow soils derived from Shale

DEPTH Cm	HOR	Sand gkg^{-1}	silt gkg^{-1}	Clay gkg^{-1}	SCR	BD gcm^{-3}	MC %	TP %	WSA %	MWD Mm
		Profile 16								
0—14	A	668	184	148	1.24	1.22	9.99	53.96	26.67	1.33
14-37	AB	608	154	238	0.65	1.29	12.84	44.15	26.23	0.95
37-58	Bt1	518	114	368	0.39	1.37	10.08	48.30	15.45	0.86
58-100	Bt2	208	404	388	1.04	1.40	10.89	47.17	15.77	0.77
100-148	Bt3	218	354	428	0.83	1.41	12.58	46.79	14.58	0.88
148-186	Bt4	108	274	618	0.44	1.49	17.66	43.77	27.88	1.21
	CV(%)	61.35	46.9	44.3	48.0	69.85	23.34	7.78	30.43	22.22
		Profile 17								
0—12	A	688	164	148	1.11	1.2	9.77	53.96	36.61	1.89
12—38	AB	608	154	238	0.65	1.35	12.64	49.06	29.55	1.21
38-57	Bt1	208	314	478	0.66	1.39	12.98	47.6	37.66	1.09
57-145	Bt2	218	303	478	0.63	1.36	12.54	48.83	18.94	0.76
145-185	Bt3	118	354	528	0.67	1.41	17.88	46.79	20.86	1.10
	CV(%)	69.79	33.41	45.3	34.2	6.18	22.29	56.68	30.16	34.39
			Profile 18							
0—11	A	688	184	128	0.70	1.12	15.00	58.12	27.60	1.08
11—44	AB	608	154	238	0.64	1.29	14.16	44.15	25.89	1.21
44-95	Bt1	408	214	378	0.57	1.32	18.08	50.57	20.46	0.97
95-123	Bt2	218	304	478	0.64	1.36	18.95	48.83	18.84	0.64
123-180	Bt3	108	374	518	0.72	1.37	10.34	48.30	19.35	0.77
	CV(%)	60.10	37	45	36	7.84	22.41	10.23	17.97	24.70

SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of physical properties of forest soils derived from Coastal plain sands

Depth (cm)	Hori	Sand	Silt	Clay	SCR	BD	MC	TP	WSA	MWD
		→	(g/kg)	←		(gcm^{-3})	→	(%)	←	(mm)
Profile 19										
0-4	Oe	858	94	48	1.96	1.10	11.85	53.34	22.25	1.13
4-18	Oa	858	64	78	0.82	1.06	8.03	59.84	22.97	1.23
18-48	A	818	74	108	0.69	1.36	10.83	43.83	34.37	1.10
48-99	AB	778	54	168	0.50	1.38	9.34	47.95	13.75	0.72
99-154	Bt1	758	54	188	0.287	1.53	10.08	42.30	31.34	2.84
154-200	Bt2	748	54	198	0.27	1.58	10.26	43.48	11.89	0.43
CV (%)		6.10	24.24	47.33	82.99	16.10	12.91	14.28	40.90	67.74
Profile 20										
0-5	Oe	858	64	78	0.82	1.20	11.69	54.56	21.13	1.56
5-18	Oa	838	74	88	0.84	1.07	8.16	59.53	29.60	2.17
18-47	A	838	54	108	0.5	1.16	8.05	56.20	15.07	1.31
47-107	AB	758	64	178	0.36	1.19	8.17	55.10	11.39	1.13
107-142	Bt1	778	34	188	0.18	1.29	8.98	51.29	12.77	0.41
142-200	Bt2	778	24	198	0.12	1.34	8.86	49.9	13.44	0.61
CV (%)		5.10	37.07	38.57	63.83	7.93	15.35	7.41	41.17	53.42
Profile 21										
0-3	Oe	868	74	58	1.28	0.90	7.05	66.12	25.8	1.68
3-21	Oa	858	64	78	0.82	0.96	7.33	63.72	19.488	1.59
21-48	A	818	64	118	0.54	0.98	6.92	63.08	17.87	1.26
48-103	AB	778	64	158	0.41	1.12	12.13	57.90	15.68	1.51
103-150	Bt1	758	54	188	0.28	1.34	8.87	48.4	11.12	1.31
150-200	Bt2	748	34	218	0.16	1.42	10.39	46.29	3.128	0.06
CV (%)		6.33	2.37	46.32	70.68	19.20	22.22	13.79	50.00	48.23

SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Physical properties of fallow soils derived from Coastal plain sand

DEPTH Cm	HOR	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	SCR	BD gcm^{-3}	MC %	TP %	WSA %	MWD Mm
	Profile 22									
0—11	A	878	64	58	1.10	1.44	12.71	45.85	22.81	2.58
11—31	AB	898	54	48	1.13	1.43	10.45	46.00	14.68	0.69
31-86	Bt1	858	94	48	1.96	1.44	11.20	45.85	19.33	1.00
86-121	Bt2	838	64	98	0.65	1.61	12.31	39.13	12.99	1.07
121-154	Bt3	818	54	128	0.42	1.61	12.55	45.85	8.41	0.81
154-200	Bt4	818	34	148	0.23	1.62	13.36	38.87	11.08	0.81
	CV (%)	3.84	32.41	49.27	68.37	6.35	8.85	8.16	35.88	61.26
	Profile 23									
0-15	A	878	94	28	3.36	1.23	10.76	53.48	15.59	0.75
15-58	AB	878	54	68	0.79	1.23	9.15	53.45	14.47	0.57
58-105	Bt1	848	44	108	0.41	1.36	9.38	48.57	19.57	0.83
105-150	Bt2	758	44	198	0.22	1.42	11.21	47.00	3.06	0.37
150-200	Bt3	778	54	168	0.32	1.57	11.99	40.83	3.99	0.42
	Cv (%)	6.83	35.75	61.28	30.00	10.48	11.53	10.79	65.68	33.91
	Profile 24									
0-14	A	878	74	48	1.54	1.44	13.42	45.78	15.15	0.98
14-56	AB	878	54	68	0.79	1.43	12.44	46	14.02	0.51
56-97	Bt1	848	64	98	0.65	1.43	11.32	46	12.28	0.63
97-149	Bt2	798	24	178	0.14	1.5	11.94	43.37	12.55	0.65
149-200	Bt3	738	64	198	0.32	1.66	15.67	34.32	26.67	1.52
	CV (%)	6.75	20	57	74	6.5	13.12	11.67	37.20	48

SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Physical properties of cultivated soils derived from Coastal plain sand

DEPTH Cm	**HOR**	**Sand** **gkg^{-1}**	**silt** **gkg^{-1}**	**Clay** **gkg^{-1}**	**SCR**	**BD** **gcm^{-3}**	**MC** **%**	**TP** **%**	**WSA** %	**MWD** Mm
	Profile25									
0-20	AP	858	54	88	0.61	1.14	8.56	57.07	12.80	0.57
20-48	AB	858	34	108	0.32	1.17	7.18	55.98	10.79	0.53
48-110	Bt1	778	34	188	0.18	1.24	8.57	53.35	11.35	0.92
110-152	Bt2	778	24	198	0.12	1.48	11.26	44.01	8.86	0.77
152-200	Bt3	758	44	198	0.22	1.52	10.81	42.64	7.00	0.42
	CV (%)	6	30	34	67	14	18	29	23	32
	Profile 26									
0-28	AP	818	94	88	1.07	0.96	7.69	62.5	19.20	1.93
28-49	AB	838	34	128	0.27	1.15	8.86	56.6	10.23	0.89
49-114	Bt1	818	64	118	0.54	1.21	13.11	54.34	19.77	1.50
114-150	Bt2	778	74	148	0.5	1.31	9.49	50.51	1.75	0.04
150-200	Bt3	738	94	168	0.56	1.54	11.19	41.97	6.79	0.84
	CV(%)	5	35	23	50	17	21	14	68	69
	Profile 27									
0-12	AP	898	24	78	0.31	1.15	9.71	56.6	13.89	1.99
12—52	AB	858	24	118	0.20	1.33	10.1	49.8	1.00	0.09
52-117	Bt1	778	34	188	0.18	1.39	9.87	47.6	6.36	1.19
117-158	Bt2	778	34	188	0.18	1.49	10.55	43.62	4.57	0.56
158-200	Bt3	758	44	198	0.22	1.64	12.48	38.1	13.20	0.87
	Cv (%)	8.00	34	34.0	29.0	13.0	11.0	15.0	72.0	76.0

SCR = Silt clay ratio, BD = Bulk density, MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, MWD = Mean weight diameter, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of chemical properties of cultivated soils derived from Falsebedded Sandstone

DEPTH (cm)	HOR	pH (KCl)	pH (H_2O)	Av.P mgkg^{-1}	Ca -----	Mg ----	K ------→	Na cmolkg^{-1}	TEB - ---←	EA -----	- ECEC -------	BS (%)	Al.sat (%)
		Profile 1											
0-9	AP	3.90	4.32	14.8	4.00	3.60	0.03	0.08	7.71	0.81	8.51	90.60	1.88
9—26	AB	3.80	5.23	15.1	1.60	1.20	0.03	0.04	2.87	0.96	3.83	86.97	8.36
26-80	Bt1	3.70	5.11	17.7	3.20	1.20	0.01	0.04	4.45	0.56	5.01	88.82	3.19
80-103	Bt2	3.70	5.00	14.6	1.20	0.80	0.02	0.01	2.03	1.20	3.23	62.85	9.91
103-180	Bt3	3.70	4.90	19.2	2.00	0.80	0.01	0.02	2.83	1.52	4.35	65.06	9.89
	CV (%)	2.37	7.21	12.34	48.6	77.6	5.00	70.61	56.9	36.6	41.64	17.35	57.67
		Profile 2											
0-9	AP	4.10	4.43	12.6	3.22	2.81	0.01	0.04	6.06	0.48	6.54	92.66	2.45
9-29	AB	3.91	4.61	14.3	4.40	0.80	0.02	0.04	5.26	0.83	6.06	86.8	3.96
29-50	Bt1	3.50	4.92	13.2	3.60	1.62	0.02	0.04	5.26	0.32	5.58	94.27	2.87
50-79	Bt2	3.81	4.80	21.4	2.40	0.81	0.03	0.01	3.24	1.04	4.28	75.72	5.61
79-120	Bt3	3.80	4.80	16.1	4.80	0.80	0.01	0.01	5.62	1.84	7.46	75.34	8.54
120-180	Bt4	3.60	4.70	15.2	2.80	1.64	0.01	0.01	4.42	1.68	6.1	72.46	6.56
	CV (%)	5.60	3.81	20.59	26.16	56.4	43.74	65.73	20.24	60.65	17.58	11.55	46.86
		Profile 3											
0-17	AP	3.51	4.00	15	3.21	2.40	0.01	0.03	5.64	1.26	6.9	81.74	4.64
17-29	AB	3.61	4.50	15.7	2.11	1.62	0.01	0.02	3.63	1.52	5.15	70.49	7.77
29-46	Bt1	3.62	4.60	15.9	1.20	0.81	0.02	0.01	2.03	1.36	3.39	59.88	16.52
46-98	Bt2	3.60	4.60	13.1	2.41	0.81	0.04	0.01	2.85	1.92	4.77	59.75	13.64
98-178	Bt3	3.22	4.70	15.9	4.14	0.80	0.01	0.01	4.82	2.16	6.98	69.05	8.02
	CV (%)	4.95	6.19	7.86	44.76	56.0	72.44	55.88	38.39	27.09	23.28	0.12	47.57

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of chemical properties of forest soils derived from Falsebedded Sandstone

DEPTH (cm)	HOR	pH (KCl)	pH (H_2O)	Av.P mgkg^{-1}	Ca	Mg	K	Na cmolkg^{-1}	TEB	EA	ECEC	BS (%)	Al.sat (%)
				Profile4									
0-1	Oe	3.70	4.51	28.30	2.00	1.21	0.01	0.13	3.34	2.16	5.50	60.73	10.18
0-3	Oa	3.60	4.00	18.30	2.40	2.00	0.01	0.09	4.50	3.36	7.86	57.25	9.16
3-9	A	3.70	4.20	15.90	2.11	1.21	0.01	0.04	3.25	2.80	6.05	53.72	11.90
9-40	AB	3.80	4.10	16.30	3.60	0.8	0.02	0.02	4.44	3.04	7.48	59.36	11.77
40-89	Bt1	3.90	4.10	15.90	2.40	2.00	0.01	0.02	4.43	2.80	7.23	61.27	8.85
89-160	Bt2	3.70	4.20	16.80	4.00	0.41	0.01	0.01	4.42	1.76	6.18	71.52	7.77
	Cv (%)	2.77	4.12	26.07	31.3	50.6	34.99	92.75	14.68	22.19	13.91	98.89	18.71
				Profile5									
0-2	Oe	3.70	5.90	28.70	4.80	3.80	0.03	0.13	8.76	1.68	10.4	84.1	6.13
2-4	Oa	3.60	4.90	17.21	4.00	3.20	0.03	0.13	7.36	2.32	9.68	76.03	6.61
4-13	A	3.70	5.30	16.50	3.60	0.80	0.02	0.06	4.48	3.28	7.76	57.73	9.28
13-49	AB	3.70	5.00	18.32	2.40	0.80	0.02	0.02	3.24	3.52	6.76	47.93	11.83
49-91	Bt1	3.80	5.10	11.71	3.60	0.80	0.21	0.02	4.62	3.28	7.90	58.48	10.13
91-158	Bt2	3.80	5.30	11.50	1.60	0.80	0.02	0.02	2.03	2.96	4.99	40.68	16.03
	CV (%)	2.03	6.79	36.21	34.5	82.7	99.00	85.13	49.78	24.79	24.86	44.67	36.50
				Profile6									
0-3	Oa	3.80	4.20	10.4	3.60	1.20	0.01	0.22	5.03	0.56	5.59	89.98	4.29
3-15	A	3.40	4.21	17.9	2.80	1.20	0.01	0.12	4.13	2.16	6.29	65.66	6.39
15-60	AB	3.60	4.81	22.3	1.60	1.20	0.01	0.01	2.82	3.12	5.94	47.47	12.12
60-131	Bt1	3.50	4.71	17.2	4.40	0.81	0.01	0.01	5.22	2.48	7.70	67.79	8.31
	CV (%)	4.78	8.73	29.00	38.53	18.18	0.00	99.9	25.47	52.36	14.50	25.71	42.86

Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of chemical properties of fallow soils derived from Falsebedded Sandstone

DEPTH (cm)	HOR	**pH (KCl)**	**pH (H_2O)**	**Av.P mgkg^{-1}**	**Ca** ----	**Mg** -----	**K** ------→	**Na cmolkg^{-}**	**TEB -** ←----	**EA -** ---	**ECEC** -----	**%BS**	**Al.sat (%)**
		Profile7											
0-18	A	3.10	4.20	16.6	1.6	0.8	0.01	0.01	2.42	2.32	4.74	51.05	11.81
18—49	AB	3.90	4.60	13.5	3.2	2.0	0.01	0.01	5.22	2.80	8.02	65.09	8.98
49-98	Bt1	3.90	4.70	23.2	2.4	1.6	0.02	0.01	4.03	2.08	5.11	78.87	10.18
98-145	Bt2	3.80	4.70	14.6	3.2	0.4	0.01	0.01	3.62	2.00	5.62	64.41	11.39
	Cv (%)	10.51	5.23	25.59	29.46	60.7	40.00	0.00	30.0	18.7	25.14	32.87	12.05
		Profile8											
0-9	A	3.90	4.10	16.1	2.0	0.8	0.01	0.04	2.85	2.88	5.73	49.74	12.57
9—35	AB	3.80	4.20	14.8	2.8	1.2	0.03	0.01	4.04	3.12	7.16	52.43	13.41
35-76	Bt1	3.90	4.30	22.8	2.8	1.6	0.02	0.01	4.43	3.28	7.71	57.46	10.38
76-140	Bt2	3.70	4.40	18.5	3.2	0.4	0.02	0.01	3.63	2.32	5.95	61.01	10.76
	Cv (%)	2.50	3.04	19.45	18.64	67	40.83	85.71	18.06	14.48	14.34	9.15	12.28
		Profile9											
0-15	A	3.80	4.10	17.7	2.0	1.6	0.01	0.06	3.67	3.12	6.79	54.05	1.18
15-33	AB	3.50	4.00	19.9	1.6	1.2	0.03	0.01	2.84	3.44	6.28	45.22	14.01
33-98	Bt1	3.50	4.30	19.7	2.8	0.8	0.01	0.01	3.62	2.8	6.42	56.39	1.12
98-130	Bt2	3.80	4.30	22.3	2.8	2.4	0.01	0.03	5.24	2.32	7.56	69.31	8.46
	Cv (%)	4.74	3.59	9.46	26.09	45.5	67	86	26.19	16.36	89.	17.69	-

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of chemical properties of forest soils derived from Shale

DEPTH (cm)	HOR	pH (KCl)	pH (H_2O)	Av.P mgkg^1	Ca --	Mg --	K --	Na → cmolkg^{-1}	TEB ← --	EA ---	ECEC ----	BS (%)	Al.sat (%)
Profile 10													
0-5	Oa	4.6	6.2	15.9	9.6	3.8	0.02	0.03	13.45	0.32	13.77	97.68	Trace
5—19	A	3.5	5.7	15.7	4.8	1.2	0.02	0.09	6.11	0.72	6.83	89.46	1.17
19-56	AB	3.4	4.8	15.7	3.2	0.8	0.01	0.03	4.04	1.60	5.64	71.63	5.67
56-98	Bt1	3.4	4.6	20.3	2.0	1.2	0.01	0.04	3.25	1.92	5.17	62.86	9.28
98-142	Bt2	3.3	4.6	16.1	3.2	1.6	0.01	0.05	4.86	3.20	8.06	60.30	9.93
142-189	Bt3	3.3	4.5	16.6	2.4	1.6	0.02	0.04	4.06	3.92	7.98	50.88	13.03
	CV (%)	14.06	14	10.69	67	63.0	37.0	48.22	63.0	72.0	39	25.04	79.37
					Profile 11								
0—3	Oa	3.9	5.6	17.0	2.0	1.2	0.01	0.24	3.45	0.24	3.69	93.50	Trace
3—10	A	3.8	5.5	15.1	5.8	2.0	0.04	0.11	7.95	0.32	8.27	96.13	0.97
10—36	AB	3.4	5.3	14.1	3.2	1.6	0.05	0.04	4.89	1.84	6.73	72.66	0.59
36-60	Bt1	3.4	5.2	15.5	2.4	1.6	0.05	0.07	4.12	3.80	7.92	52.02	10.10
60-110	Bt2	3.3	4.9	19.2	2.8	1.6	0.04	0.04	4.48	4.48	8.96	50.00	12.50
110-185	Bt3	3.3	4.8	16.5	1.6	0.4	0.03	0.03	2.03	4.72	6.75	30.07	17.78
	CV (%)	7.5	6.1	11.0	50.0	39	41	89	44.0	80.0	26.43	40.00	------
					Profile 12								
0—3	Oa	3.8	5.7	25.0	6.4	3.6	0.04	0.12	10.16	0.4	10.56	96.21	Trace
3—14	A	3.6	5.7	19.7	3.6	1.2	0.03	0.04	4.87	0.64	5.51	88.39	Trace
14-50	AB	3.5	5.6	16.6	2.4	2.0	0.03	0.05	4.48	1.52	6.00	74.67	8.00
50-89	Bt1	3.4	4.5	18.6	4.0	1.2	0.02	0.05	5.27	1.76	7.03	74.96	6.83
89-127	Bt2	3.3	4.4	20.3	3.2	0.8	0.06	0.07	4.89	3.12	8.01	61.05	10.99
127-189	Bt3	3.2	4.3	17.7	2.8	2.0	0.02	0.07	4.89	3.84	8.73	56.01	12.83
	Cv (%)	6.23	13.9	14.96	38.1	56	45	43.17	37.0	72.34	24.45	20.46	84.16

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv=Highvariation (Wilding,1985).

Profile distribution of chemical properties of Cultivated soils derived from Shale

DEPTH (cm)	HOR	**pH (KCl)**	**pH (H_2O)**	**Av.P** mgkg^{-1}	**Ca** ----	**Mg** ----	**K** ---- →	**Na** cmolkg^{-1}	**TEB** ←---	**EA** ----	**ECEC** ----	**BS (%)**	**Al.sat (%)**
							profile13						
0-12	AP	3.7	4.60	19.0	2.00	1.20	0.01	0.04	3.26	0.4	3.3	98.79	4.85
12-66	AB	3.6	4.50	23.7	2.00	0.80	0.04	0.02	2.86	0.48	3.34	85.63	7.19
66-104	Bt1	3.5	4.30	27.3	1.20	0.80	0.02	0.02	2.04	1.28	3.32	61.45	12.05
104-143	Bt2	3.4	4.20	23.4	3.61	0.80	0.01	0.02	4.43	1.68	6.11	72.5	7.86
143-180	Bt3	3.4	4.10	20.1	1.20	0.60	0.02	0.02	1.84	2.64	4.48	41.07	12.50
	CV (%)	4.0	4.80	14.5	49.0	26.0	61.24	37.27	36.07	71.38	29.82	30.88	37.00
							Profile 14						
0-9	AP	3.60	4.20	20.3	1.60	1.2	0.02	0.01	2.83	0.56	3.39	83.48	4.72
9-70	AB	3.70	4.30	23.0	1.60	1.2	0.03	0.01	2.84	0.72	3.56	79.78	17.98
70-89	Bt1	3.60	4.20	26.3	1.20	0.8	0.03	0.01	2.04	1.52	3.56	57.3	12.08
89-117	Bt2	3.50	4.30	28.2	4.00	0.4	0.02	0.01	4.43	2.24	6.67	66.42	7.20
117-180	Bt3	3.40	4.10	18.1	3.60	2.4	0.01	0.01	6.02	2.72	8.74	68.88	10.07
	CV (%)	3.20	1.98	17.9	54.0	62.4	38.03	----	43.85	60.39	46.60	14.83	48.70
							Profile 15						
0-9	AP	3.80	4.20	23.6	2.02	0.8	0.01	0.07	2.88	0.72	3.60	80.00	6.67
9-68	AB	3.60	4.50	22.5	2.01	1.2	0.02	0.01	3.23	0.8	4.03	80.15	5.96
68-105	Bt1	3.60	4.60	20.6	4.00	0.8	0.01	0.01	4.82	1.04	5.86	82.42	4.10
105-133	Bt2	3.60	4.20	18.5	4.40	0.8	0.04	0.01	5.25	1.68	6.93	75.76	1.15
133-185	Bt3	3.50	4.00	18.3	1.20	0.8	0.02	0.01	2.03	2.16	4.19	48.45	19.09
	CV (%)	3.03	5.69	11.39	51.37	20.3	61.24	---	37.15	48.41	28.71	19.26	93.01

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of chemical properties of fallow soils derived from Shale

DEPTH (cm)	HOR	pH (KCl)	pH (H_2O)	Av.P mgkg^{-1}	Ca ---	Mg ---	K ----	Na → cmolkg^{-1} ←	TEB ---	EA ---	ECEC ---	BS (%)	Al.sat (%)
	Profile16												
0—14	A	3.7	4.0	20.6	4.4	1.2	0.01	0.01	5.62	0.56	6.18	90.94	Trace
14-37	AB	3.8	4.1	24.8	1.6	1.2	0.04	0.01	2.85	0.8	3.65	78.08	Trace
37-58	Bt1	3.7	4.1	23.8	3.6	2.8	0.02	0.01	6.43	0.72	7.15	89.93	2.24
58-100	Bt2	3.9	4.2	21.6	4.0	0.8	0.02	0.01	4.83	0.88	5.71	84.59	Trace
100-148	Bt3	3.5	4.3	22.5	4.4	1.2	0.01	0.01	5.62	0.4	6.02	93.36	Trace
148-186	Bt4	3.5	4.1	21.6	3.6	1.2	0.01	0.01	4.82	0.96	5.78	83.39	Trace
	CV (%)	4.35	2.4	6.94	29	50	50.0	0.00	24.3	29.17	20.03	6.57	------
	Profile 17												
0—12	A	3.4	4.2	22.7	3.2	2.1	0.01	0.01	3.42	0.48	3.90	87.69	Trace
12—38	AB	3.6	4.3	27.0	5.6	1.2	0.02	0.01	6.83	0.88	7.71	88.59	3.11
38-57	Bt1	3.8	4.4	20.6	3.6	1.2	0.02	0.01	4.83	0.56	5.39	89.61	Trace
57-145	Bt2	3.9	4.3	16.8	2.0	1.6	0.01	0.02	3.63	0.56	4.19	86.64	Trace
145-185	Bt3	3.6	4.4	19.4	4.4	0.8	0.01	0.02	5.23	0.08	5.28	99.05	Trace
	CV (%)	5.33	1.94	18.0	36	34	39	28.75	42.47	55.90	28.34	5.54	-----
	Profile18												
0—11	A	3.8	4.4	25.6	3.2	2.0	0.01	0.02	5.23	0.24	5.47	95.61	Trace
11—44	AB	3.7	4.3	19.9	2.4	0.8	0.01	0.01	3.22	0.16	3.38	95.27	Trace
44-95	Bt1	3.8	4.4	16.8	2.4	1.6	0.01	0.01	4.02	0.16	4.18	96.17	1.91
95-123	Bt2	3.5	4.2	16.8	3.6	0.8	0.02	0.01	4.43	0.16	4.59	96.51	1.31
123-180	Bt3	3.6	4.3	30.3	2.4	2.0	0.02	0.01	4.43	0.24	4.67	94.86	3.43
	CV (%)	3.5	1.46	27.17	20	42	38.6	37.25	17.14	22.81	17.10	0.69	-----

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of chemical properties of forest soils derived from Coastal plain sand

DEPTH (cm)	HOR	pH (KCl)	pH (H_2O)	Av.P $mgkg^{-1}$	Ca -- ---	Mg ----	K ------	Na cmol/kg	TEB ----	EA -- -----	ECEC -----	BS (%)	Al.sat (%)
				Profile 19									
0-4	Oe	4.21	5.01	28.13	5.8	2.80	0.27	0.16	9.03	1.62	10.65	84.79	6.67
4—18	Oa	3.80	4.78	26.8	4.8	2.40	0.27	0.16	7.63	2.08	9.71	78.58	9.78
18-48	A	3.60	4.35	20.00	2.8	1.60	0.06	0.09	4.55	1.76	6.31	72.11	25.09
48-99	AB	3.20	4.20	16.10	2.4	2.00	0.10	0.09	4.58	1.36	5.94	77.1	17.51
99-154	Bt1	3.20	4.20	20.00	2.8	1.60	0.12	0.11	4.63	1.6	6.24	74.20	15.38
154-200	Bt2	3.40	4.80	17.80	2.8	1.20	0.08	0.13	4.21	1.28	5.49	76.69	14.81
	CV (%)	11.00	8.00	23.00	39	31	63	26	35	18	30	5.63	41.81
				Profile 20									
0-5	Oe	3.5	4.49	25.76	5.00	2.00	0.11	0.1	7.21	1.44	8.65	83.35	9.48
5—18	Oa	3.3	4.36	20.40	4.00	2.00	0.097	0.12	6.23	1.76	7.98	78.07	12.03
18-47	A	3.3	4.31	17.50	3.20	1.60	0.20	0.087	5.09	1.92	7.01	72.61	12.55
47-107	AB	3.3	4.26	19.00	2.80	1.60	0.08	0.12	4.6	1.61	6.21	74.07	18.04
107-142	Bt1	3.2	5.18	16.10	3.60	2.00	0.097	0.09	5.78	1.22	6.84	82.51	12.87
142-200	Bt2	3.3	4.44	18.70	4.00	2.00	0.15	0.09	6.24	1.36	7.57	82.24	7.40
	CV (%)	3.00	8.00	17.00	20.00	11.00	37.00	15.00	16.00	17.00	12.00	59.00	29.90
				Profile 21									
0-3	Oe	3.9	5.01	26.63	4.60	2.30	0.11	0.1	7.1	1.53	8.63	82.27	9.50
3—21	Oa	3.5	5.76	23.4	4.00	2.80	0.04	0.04	6.88	1.53	8.41	81.81	10.23
21-48	A	3.4	4.39	17.5	4.20	1.60	0.02	0.09	5.91	1.92	7.83	75.48	11.24
48-103	AB	3.3	4.44	18.7	2.80	2.00	0.08	0.02	4.9	1.54	6.44	76.09	14.91
103-150	Bt1	3.8	5.35	20.0	4.60	2.00	0.11	0.09	6.8	0.70	7.5	90.66	3.73
150-200	Bt2	3.5	4.90	16.1	4.00	2.00	0.12	0.09	6.2	1.53	7.73	80.21	8.54
	CV (%)	7.0	11.00	19.00	16.1	19.40	52.2	46.01	13.00	28.10	10.11	68.00	37.72

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985)

Profile distribution of chemical properties of fallow soils derived from Coastal plain sand

DEPTH	HOR	pH (KCl)	pH (H$_2$O)	Av.P mgkg^{-1}	Ca -----	Mg ---	K ------	Na cmolkg^{-1}	TEB ------	EA - ----	ECEC -----	%BS	Al.sat (%)
Profile 22													
0—11	A	3.2	4.17	18.1	3.6	2.0	0.13	0.11	5.84	1.92	7.76	75.26	15.46
11—31	AB	3.3	4.45	17.8	3.6	2.4	0.10	0.07	6.17	1.79	7.96	77.51	21.36
31-86	Bt1	4.9	6.03	16.1	4.0	2.8	0.14	0.13	7.07	0.51	9.04	78.21	2.66
86-121	Bt2	3.8	5.30	17.1	2.4	2.0	0.12	0.01	4.61	1.04	5.65	81.59	4.25
121-154	Bt3	3.7	5.02	17.5	3.6	2.4	0.12	0.06	6.18	1.84	8.02	77.06	4.99
154-200	Bt4	3.8	5.11	18.34	4.6	2.8	0.11	0.06	7.57	1.55	9.12	83.00	4.72
	CV (%)	16.0	13.00	46.00	20.0	15	12.00	33.00	17.00	39.0	16.11	37.21	85.74
Profile 23													
0-15	A	3.5	4.47	17.4	4.0	2.40	0.10	0.04	6.54	3.6	10.14	64.00	23.67
15-58	AB	3.5	4.42	20.9	3.6	1.20	0.09	0.18	5.07	5.04	10.11	50.00	14.24
58-105	Bt1	3.5	4.81	19.3	2.8	1.60	0.05	0.07	4.52	1.44	5.96	75.00	16.11
105-150	Bt2	3.4	4.55	20.9	3.2	1.60	0.09	0.1	4.99	1.12	6.1	81.00	9.18
150-200	Bt3	3.6	4.88	21.9	2.8	1.20	0.10	0.12	4.22	1.36	5.58	75.00	17.20
	CV (%)	2.0	4.00	88.0	16.0	31.0	24.0	52.1	0.18	69.0	31.2	18.0	32.59
Profile 24													
0-14	A	4.0	5.47	20.4	4.6	2.8	0.11	0.06	7.57	1.55	9.12	83.00	4.77
14-56	AB	4.1	5.42	20.9	4.0	2.8	0.14	0.13	7.07	0.51	9.04	78.21	2.66
56-97	Bt1	3.5	4.89	19.3	2.4	2.0	0.12	0.1	4.61	1.04	5.65	81.59	4.25
97-149	Bt2	3.6	4.95	22.9	3.6	2.0	0.13	0.11	5.84	1.92	7.76	75.26	15.54
149-200	Bt3	3.9	5.88	21.9	3.6	2.4	0.12	0.06	6.18	1.84	8.02	77.06	4.99
	CV (%)	7.0	8.00	7.00	22	16.67	9.11	33.00	19.0	43.0	18.0	4.06	80.39

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of chemical properties of cultivated soils derived from Coastal plain sand

DEPTH cm	HOR	pH (KCl)	pH (H_2O)	Av.P mgkg^{-1}	Ca	Mg	K	Na	TEB	EA	ECEC	BS	Al.sat
					----	-----	---- →	----	cmolkg^{-1}	← ---	---------	(%)	(%)
				Profile25									
0-20	AP	3.8	5.52	27.7	2.40	2.00	0.08	0.10	4.59	0.56	5.15	89.13	10.87
20-48	AB	3.9	5.13	17.1	3.20	1.60	0.1	0.10	4.99	1.12	6.11	81.66	10.48
48-110	Bt1	3.9	5.67	15.9	4.00	1.20	0.09	0.19	5.48	1.36	6.84	80.11	17.54
110-152	Bt2	3.3	4.46	17.5	4.00	2.80	0.11	0.17	7.08	1.2	8.28	85.51	3.87
152-200	Bt3	3.4	4.40	20.4	3.20	2.11	0.11	0.06	5.36	1.04	6.4	83.75	6.25
	CV (%)	7.86	11.6	24.12	20.00	31.1	13.3	44.0	17.00	29.00	18.00	42.00	53.36
				Profile26									
0-28	AP	3.4	4.91	41.6	4.1	2.6	0.12	0.12	6.84	0.64	7.48	91.44	3.21
28-49	AB	3.4	4.64	20.0	2.8	1.6	0.14	0.09	4.63	1.84	6.47	71.56	17.31
49-114	Bt1	3.5	4.18	18.7	5.6	3.2	0.11	0.1	9.01	1.44	10.45	86.22	9.95
114-150	Bt2	3.4	4.90	19.3	4.2	2.4	0.09	0.13	6.62	1.2	7.82	84.66	10.26
150-200	Bt3	3.6	4.50	19.5	4.0	2.1	0.12	0.14	6.26	1.68	7.94	78.84	10.08
	CV (%)	2.6	6.58	42.00	24.00	26.00	16.00	18.00	24.00	35.00	18.30	9.22	49.01
				Profile27									
0-12	AP	3.7	5.51	27.45	3.20	2.00	0.11	0.06	5.36	1.04	6.4	83.75	6.25
12—52	AB	3.89	5.23	17.1	4.20	1.20	0.09	0.19	5.48	1.36	6.84	80.12	17.54
52-117	Bt1	3.76	5.67	16.46	4.10	2.40	0.09	0.13	6.62	1.2	7.82	84.66	10.23
117-158	Bt2	3.40	4.56	17.5	2.80	1.60	0.14	0.09	4.63	1.84	6.47	71.56	17.31
158-200	Bt3	3.50	4.74	21.22	2.80	1.20	0.11	0.06	4.17	1.9	6.07	68.7	14.82
	Cv (%)	5.4	9.3	23.00	18.00	31.00	19.00	52.00	18.00	26.00	10.0	9.31	36.93

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985)

Appendix 2: Profile distribution of Carbon and Nitrogen forms and sequestration in soils derived from different parent materials

Profile distribution of Carbon and Nitrogen forms and sequestration in cultivated soils derived from Falsebedded Sandstone

DEPTH Cm	**HOR**	**TN** mgkg^{-1}	**NO_3^- mgkg^{-1}**	**NH_4^+ mgkg^{-1}**	**NStock gNm^{-2}**	**TotalC gkg^{-1}**	**Org.C gkg^{-1}**	**OM gkg^{-1}**	**INO.C gkg^{-1}**	**CStock gCm^{-2}**
			profile1							
0-9	AP	4.51	1.58	0.26	41.00	44.4	18.8	32.41	25.6	1709
9-26	AB	1.75	0.75	0.20	33.32	46.1	8.9	15.34	37.2	1695
26-80	Bt1	1.26	0.57	0.21	82.33	45.4	6.1	10.52	39.3	3986
80-103	Bt2	1.75	0.37	0.27	48.70	62.9	6.1	10.52	56.8	1697
103-180	Bt3	2.81	0.44	0.17	309.41	66.4	5.7	9.83	60.7	6276
	CV(%)	**53.77**	65.43	19.43	99.9	20.14	60.97	60.95	99.9	66.59
			profile2							
0-9	AP	5.00	1.73	0.23	40.50	39.7	16.8	28.96	22.9	1361
9-29	AB	4.46	1.69	0.12	94.55	21.6	13.3	22.93	8.3	28120
29-50	Bt1	3.32	0.44	0.96	83.66	45.1	8.8	15.17	36.3	2218
50-79	Bt2	2.68	0.34	0.06	94.04	35.6	5.7	9.83	29.9	2000
79-120	Bt3	3.16	0.29	0.12	176.20	69.3	6.7	11.55	62.6	3736
120-180	Bt4	2.40	0.22	0.21	213.12	9.4	7.1	12.24	2.3	6305
	CV(%)	29.11	91.23	99.9	55.04	55.94	45.00	44.99	79.96	57.78
			profile3							
0-17	AP	5.13	1.24	0.16	97.10	46.3	17.00	29.31	29.3	3237
17-29	AB	4.27	0.73	0.13	66.61	55.8	10.9	18.79	44.9	1726
29-46	Bt1	2.68	0.32	0.12	52.39	51.5	7.7	13.28	43.8	1505
46-98	Bt2	4.11	0.19	0.23	337.68	82.2	8.1	13.96	74.1	6655
98-178	Bt3	0.75	0.14	0.64	94.42	85.7	5.4	9.34	80.3	6826
	CV(%)	50.73	88.36	87.56	90.88	28.45	45.46	45.39	39.91	65.12

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Carbon and Nitrogen forms and sequestration in forest soils derived from Falsebedded Sandstone .

DEPTH cm	HOR	TN $mgkg^{-1}$	NO_3^- $mgkg^{-1}$	NH_4^+ $mgkg^{-1}$	NStock gNm^{-2}	total C gkg^{-1}	Org.C gkg^{-1}	OM gkg^{-1}	INO.C gkg^{-1}	CStock gCm^{-2}
			PROFILE 4							
0-1	Oe	19.97	1.94	0.58	14.18	120.00	42.3	72.93	77.7	300
1--3	Oa	13.74	3.06	0.75	27.76	107.00	26.4	45.51	80.6	533
3--9	A	11.22	5.58	1.33	67.99	97.7	27.4	47.24	70.3	1660
9--40	AB	0.59	0.71	0.19	227.95	99.7	19.5	33.62	80.2	7496
40-89	Bt1	0.46	0.39	0.23	307.46	122.5	13.9	23.96	108.6	9331
89-160	Bt2	0.80	0.42	0.43	802.53	124.00	11.5	19.83	112.5	11594
	CV(%)	--	---	71.77	---	10.57	47.7	47.7	19.99	95.68
			PROFILE 5							
0-2	Oe	14.88	0.93	0.71	24.11	102.3	43.7	75.32	58.62	708
2--4	Oa	11.14	3.51	0.75	18.27	100.4	40.8	70.54	59.6	669
4--13	A	12.57	1.65	0.88	119.92	91.4	26.8	46.2	64.6	2557
13-49	AB	7.25	0.41	0.17	328.86	128.00	15.4	26.55	112.6	6985
49-91	Bt1	0.63	0.18	0.15	358.34	125.4	13.2	22.76	112.2	7484
91-158	Bt2	0.78	0.30	0.26	715.04	122.5	13.3	22.93	109.2	12208
	CV(%)	77.24	---	67.88	---	13.86	54.5	54.57	32.16	89.89
				PROFILE 6						
0--3	Oa	21.00	0.51	0.24	51.66	148.5	70.4	121.4	78.1	1731
3--15	A	16.34	0.67	2.47	188.24	75.7	49.3	84.99	26.4	5679
15-60	AB	8.09	0.22	4.41	436.86	139.7	19.1	32.93	120.6	10314
60-131	Bt1	5.51	0.21	3.70	528.13	150.8	12.2	21.03	138.6	11694
	CV(%)	56.46	56.55	67.56	72.96	27.69	71.7	71.74	54.92	83.78

Oe = Hemic horizon, Oa = Sapric horizon, Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation.

Profile distribution of Carbon and Nitrogen forms and sequestration in fallow soils derived from Falsebedded Sandstone

DEPTH cm	**HOR**	**TN mgkg^{-1}**	**NO$_3^-$ mgkg^{-1}**	**NH$_4^+$ mgkg^{-1}**	**NStock gNm^{-2}**	**total C gkg^{-1}**	**Org.C gkg^{-1}**	**OM gkg^{-1}**	**INO.C gkg^{-1}**	**CStock gCm^{-2}**
			Profile7							
0-18	A	8.99	2.46	2.46	145.61	81.8	22.2	38.38	59.6	3596
18--49	AB	4.25	0.18	0.07	131.90	107.6	13.7	23.62	93.9	4247
49-98	Bt1	2.85	0.16	0.09	155.01	110.8	12.2	21.03	98.6	6636
98-145	Bt2	2.68	0.11	0.06	172.57	111.1	11.1	19.14	100	7147
	CV (%)	62.87	99.9	-	11.28	13.72	34.10	34.27	21.73	32.32
		Profile8								
0-9	A	6.36	0.81	0.11	51.52	77.1	22.4	38.62	54.7	1814
9--35	AB	2.75	0.59	0.22	84.37	74.8	15.3	26.38	59.5	4694
35-76	Bt1	2.73	0.22	0.21	138.79	106.7	11.5	19.83	95.2	5847
76-140	Bt2	4.67	0.08	0.08	403.49	109.1	8.4	14.48	100.7	7258
	CV (%)	42.26	77.89	43.63	94.41	20.12	41.90	41.89	30.66	47.13
		Profile9								
0-15	A	1.14	0.74	0.07	20.69	86.8	19.2	33.2	67.6	3485
15-33	AB	2.70	0.38	0.18	60.75	101.6	14.8	25.52	86.8	3330
33-98	Bt1	4.73	0.24	0.16	415.06	110.00	10.4	17.93	99.6	9126
98-130	Bt2	3.53	0.16	0.06	159.27	118.3	8.4	14.48	109.9	3790
	CV (%)	49.84	67.88	51.85	87.99	12.9	36.44	36.59	20.03	56.81

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Carbon and Nitrogen forms and sequestration in Forest soils derived from Shale

DEPTH cm	HOR	TN $mgkg^{-1}$	NO_3^- $mgkg^{-1}$	NH_4+ $mgkg^{-1}$	N stock gNm^{-2}	total C gkg^{-1}	Org.C gkg^{-1}	OM gkg^{-1}	INO.C gkg^{-1}	Cstock gCm^{-2}
				profile10						
0-5	Oa	11.42	0.74	1.04	49.68	59.9	43.5	75.99	16.4	1892
5--19	A	14.92	1.59	0.63	202.61	28.4	24.9	42.93	3.5	3381
19-56	AB	2.71	0.42	0.26	126.34	31.5	12.1	20.86	19.4	5641
56-98	Bt1	2.68	0.36	0.28	142.95	40.7	11.8	20.34	28.9	6294
98-142	Bt2	3.80	0.34	0.28	224.05	78.6	8.1	13.96	70.5	4776
142-189	Bt3	2.57	0.18	0.19	161.86	81.00	7.5	12.93	73.5	4724
	CV(%)	85.28	85.77	74.13	54.04	43.59	77.84	78.58	83.50	35.78
				Profile11						
0--3	Oa	10.63	0.96	0.97	38.81	68	41.2	71.03	20.6	1014
3--10	A	15.75	1.07	0.51	116.87	45.2	35.6	61.37	9.6	2642
10--36	AB	3.60	0.58	0.41	117.00	39.8	23.9	41.2	15.9	7768
36-60	Bt1	4.19	0.18	0.48	129.72	51	13.1	22.58	37.9	4056
60-110	Bt2	4.19	0.14	0.41	278.64	82.3	12.5	21.55	69.8	8313
110-185	Bt3	2.87	0.29	0.43	292.74	79.8	8.2	14.14	71.6	8364
	Cv(%)	75.35	75.07	40.69	62.21	29.81	60.38	60.38	72.78	59.89
				Profile12						
0--3	Oa	15.97	1.07	0.47	38.81	52.1	41.6	71.72	10.5	1011
3--14	A	15.51	1.01	0.84	163.79	30.1	20.5	35.34	9.6	2165
14-50	AB	3.92	0.11	0.76	182.05	26.6	14.5	25	12.1	6734
50-89	Bt1	2.18	0.09	0.39	117.33	40.3	9.7	16.72	30.6	5221
89-127	Bt2	2.18	0.22	0.43	113.49	61.7	8.6	14.82	53.1	4477
127-189	Bt3	2.87	0.14	0.42	245.56	65.6	7.7	13.27	57.9	6588
	Cv(%)	94.58		35.89	49.14	35.38	75.49	75.99	75.99	53.61

Oa = Sapric horizon, Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Carbon and Nitrogen forms and sequestration in Cultivated soils derived from Shale

DEPTH cm	**HOR**	**TN $mgkg^{-1}$**	**NO_3^- $mgkg^{-1}$**	**NH_4^+ $mgkg^{-1}$**	**NStock gNm^{-2}**	**totalC gkg^{-1}**	**Org.C gkg^{-1}**	**OM gkg^{-1}**	**INO.C gkg^{-1}**	**Cstock gCm^{-2}**
			Profile13							
0-12	AP	1.42	0.69	0.51	21.13	29.6	21.00	36.2	8.6	3125
12--66	AB	1.15	0.38	0.26	79.49	17.8	6.6	11.38	11.2	4562
66-104	Bt1	1.49	0.17	0.14	76.44	34.7	7.6	13.1	27.1	3899
104-143	Bt2	1.76	0.16	0.42	92.66	44.00	7.3	12.59	36.7	3844
143-180	Bt3	3.19	0.28	0.94	161.70	58.00	7.9	13.62	50.1	4005
	CV(%)	44.71	64.50	67.71	58.29	41.16	60.75	60.74	53.97	13.19
			Profile14							
0--9	AP	1.35	0.57	0.35	15.92	23.7	16.1	27.76	7.6	1898
9--70	AB	1.30	0.91	0.25	103.88	22.2	8.6	14.83	13.6	6872
70-89	Bt1	1.84	0.87	0.19	47.20	35.8	7.4	12.76	28.4	1898
89-117	Bt2	2.21	0.51	0.11	87.87	57.7	7.6	13.1	50.1	3022
117-180	Bt3	2.72	0.65	0.17	251.90	81.00	7.7	13.28	73.3	7131
	CV(%)	31.77	25.47	43.09	89.73	56.84	39.34	39.34	78.44	63.20
			Profile15							
0-9	AP	5.37	0.80	0.85	58.96	28.00	18.00	31.03	10	1976
9--68	AB	1.98	0.31	1.05	147.19	21.60	8.7	15	12.9	6468
68-105	EB	2.21	0.27	1.01	103.03	27.00	7.00	12.07	20	3263
105-133	Bt1	1.81	0.25	0.83	71.46	34.2	8.3	14.31	25.9	3277
133-185	Bt2	1.81	0.27	0.10	133.65	54.6	9.5	16.38	45.1	7015
100-148	Bt2	1.15	0.29	0.07	77.83	19.2	6.9	11.9	12.3	4670
148-186	Bt3	2.10	0.19	0.06	118.90	67.00	8.9	15.34	58.1	5039
	CV(%)	58.33	63.16	50.65	37.13	38.78	42.72	42.68	61.15	50.23

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Carbon and Nitrogen forms and sequestration in Fallow soils derived from Shale

DEPTH Cm	HOR	TN $mgkg^{-1}$	NO_3^- $mgkg^{-1}$	NH_4^+ $mgkg^{-1}$	N Stock gNm^{-2}	total C gkg^{-1}	Org.C gkg^{-1}	OM gkg^{-1}	INO.C gkg^{-1}	C Stock gCm^{-2}
				Profile16						
0--14	A	2.75	1.12	0.11	46.97	21.6	15.2	26.21	6.4	2596
14-37	AB	2.11	0.47	0.16	62.60	31.1	8.7	15	22.2	2581
37-58	Bt1	2.18	0.21	0.02	62.72	16.6	11.1	19.14	5.5	3194
58-100	Bt2	1.84	0.35	0.03	108.19	19.4	6.6	11.38	12.8	3881
100-148	Bt3	1.15	0.29	0.07	77.83	19.2	6.9	11.9	12.3	4667
148-186	Bt4	2.10	0.19	0.06	118.90	67.00	8.9	15.34	58.1	5039
	Cv (%)	25.74	79.77	69.01	35.57	65.89	33.45	33.45	---	28.61
				Profile17						
0--12	A	1.74	1.16	0.04	25.06	24.6	17.7	30.52	6.9	2549
12--38	AB	1.82	0.79	0.19	63.88	16.2	11.2	19.31	5	3931
38-57	Bt1	2.50	0.63	0.08	66.03	15.3	11.5	19.83	3.8	3037
57-145	Bt2	1.73	0.82	0.10	208.24	13.6	8.4	14.48	5.2	10053
145-185	Bt3	1.15	0.16	0.15	64.86	74.9	7.00	12.07	67.9	3948
	Cv (%)	26.8	50.69	51.82	82.67	90.08	36.89	36.90	---	64.84
				Profile18						
0--11	A	18.38	0.99	0.91	226.44	24.2	17.8	30.69	6.4	2193
11--44	AB	2.00	0.42	0.05	85.14	22.8	12.7	21.9	10.1	5406
44-95	Bt1	2.10	0.22	0.06	141.37	21.7	10.1	17.41	11.6	6799
95-123	Bt2	3.19	0.18	0.08	121.48	81.3	10.1	17.41	71.2	3846
123-180	Bt3	2.65	0.21	0.03	206.94	95.3	9.2	15.86	86.1	7184
	Cv (%)		84.23		37.84	73.73	29.27	29.28	---	40.95

Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Carbon and Nitrogen forms and sequestration in forest soils derived from Coastal plain sand

DEPTH cm	HOR	TN mgkg^{-1}	NO3 mgkg^{-1}	NH4 mgkg^{-1}	N stock gNm^{-2}	total C gkg^{-1}	Org.C gkg^{-1}	OM gkg^{-1}	INO.C gkg^{-1}	Cstock gCm^{-2}
			profile19							
0-4	Oe	12.00	0.24	0.13	53	85.01	42.00	72.41	43.01	1848
4--18	Oa	4.00	0.10	0.05	60	35.70	16.63	28.67	19.07	2468
18-48	A	1.00	0.07	0.08	41	61.10	8.11	13.98	52.99	3309
48-99	AB	2.00	0.05	0.19	141	72.32	6.90	11.9	65.42	4856
99-154	Bt1	2.00	0.05	0.03	168	67.50	6.10	10.52	61.4	5133
154-200	Bt2	2.10	0.04	0.20	145	60.82	7.21	12.43	53.61	4975
	CV(%)	---	81.79	63.72	55.43	25.70	96.76	96.75	33.88	37.73
			profile20							
0-5	Oe	11.20	0.20	0.19	67	95.82	17.91	30.88	77.91	1075
5--18	Oa	10.20	0.13	0.18	142	56.91	52.60	90.68	4.31	7317
18-47	A	6.00	0.08	0.03	202	61.61	9.00	15.52	52.61	3028
47-107	AB	6.00	0.16	0.05	428	46.80	7.83	13.5	38.97	5591
107-142	Bt1	6.10	0.15	0.05	275	57.10	6.80	11.72	50.3	3070
142-200	Bt2	5.00	0.10	0.02	387	70.50	6.32	10.9	64.18	4912
	CV(%)	34.97	32.01	89.83	56.19	26.29	----	---	52.43	53.22
			Profile21							
0-3	Oe	17.50	0.30	0.28	47	75.70	50.00	86.2	25.7	1350
3--21	Oa	9.11	0.14	0.09	157	39.50	15.73	27.12	23.77	2718
21-48	A	6.00	0.08	0.07	159	44.22	9.40	16.21	32.82	2487
48-103	AB	4.20	0.11	0.05	259	65.10	8.41	14.5	56.69	5181
103-150	Bt1	5.00	0.26	0.04	315	46.62	5.67	9.78	40.95	3571
150-200	Bt2	5.00	0.30	0.03	355	67.10	7.31	12.6	59.79	5190
	CV(%)	64.77	49.93	99.42	53.41	26.22	---	----	38.62	45.16

Cv = Coefficient of variation, Cv $\leq$ 15% = Low variation, Cv > 15 $\leq$ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Carbon and Nitrogen forms and sequestration in fallow soils derived from Coastal plain sand

DEPTH cm	HOR	**TN mgkg^{-1}**	**NO_3^- mgkg^{-1}**	**NH_4^+ mgkg^{-1}**	**Nstock gNm^{-2}**	**total C gkg^{-1}**	**Org.C gkg^{-1}**	**OM gkg^{-1}**	**INO.C gkg^{-1}**	**Cstock gCm^{-2}**
			Profile22							
0--11	A	12.00	0.30	0.06	190	90.20	15.91	27.43	74.29	2520
11--31	AB	12.10	0.11	0.05	346	95.10	11.12	19.17	83.98	3180
31-86	Bt1	8.20	0.09	0.04	65	81.62	8.10	13.96	73.52	6415
86-121	Bt2	8.20	0.08	0.03	462	85.40	7.00	12.06	78.4	3944
121-154	Bt3	0.60	0.23	0.03	319	78.41	5.44	9.38	72.97	2890
154-200	Bt4	6.00	0.18	0.02	447	88.24	5.10	8.79	83.14	3801
	CV(%)	54.49	52.66	38.39	50	69.59	46.87	46.88	63.64	36.75
			profile23							
0-15	A	3.00	0.06	0.09	55	52.72	15.50	26.72	37.22	2860
15-58	AB	10.00	0.40	0.16	528	89.80	9.74	16.79	80.06	5152
58-105	Bt1	6.00	0.14	0.04	384	83.61	6.80	11.72	76.81	4347
105-150	Bt2	6.00	0.18	0.03	383	98.10	5.14	8.86	92.94	3285
150-200	Bt3	7.10	0.14	0.02	557	79.73	4.40	7.59	75.33	3454
	CV(%)	39.19	69.72	85.75	52.24	21.23	54.23	54.22	28.83	24.11
			Profile24							
0-14	A	11.00	0.25	0.09	222	138.90	16.70	28.79	122.2	3367
14-56	AB	8.10	0.13	0.05	487	108.91	9.20	15.86	99.71	5526
56-97	Bt1	9.20	0.09	0.03	539	99.40	7.90	13.62	91.5	4632
97-149	Bt2	4.00	0.08	0.02	312	82.50	6.30	10.86	76.2	4914
149-200	Bt3	8.30	0.10	0.02	703	94.13	4.80	8.28	89.33	4064
	CV(%)	31.68	53.57	70.21	41.97	20.36	51.47	51.47	17.75	18.31

Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985).

Profile distribution of Carbon and Nitrogen forms and sequestration in cultivated soils derived from Coastal plain sand

DEPTH cm	**HOR**	**TN mgkg^{-1}**	**NO_3^- mgkg^{-1}**	**NH_4^+ mgkg^{-1}**	**NStock gNm^{-2}**	**total C gkg^{-1}**	**Org.C gkg^{-1}**	**OM gkg^{-1}**	**INO.C gkg^{-1}**	**Cstock gCm^{-2}**
				Profile25						
0-20	AP	8.00	0.14	0.05	182	27.50	8.31	14.33	19.19	1895
20-48	AB	8.00	0.04	0.03	262	82.10	8.30	14.32	73.8	2719
48-110	Bt1	8.00	0.06	0.03	615	65.71	7.20	12.41	58.51	5535
110-152	Bt2	6.00	0.09	0.04	373	64.20	5.61	9.67	58.59	3487
152-200	Bt3	7.00	0.11	0.06	511	67.40	4.92	8.48	62.48	3590
	CV(%)	12.09	45.15	30.95	45.47	32.99	22.58	22.60	37.99	39.27
				profile26						
0-28	AP	8.00	2.00	0.09	215.	31.00	11.12	19.17	19.88	2989
28-49	AB	7.00	0.18	0.04	169.	67.50	6.80	11.72	60.7	1642
49-114	Bt1	7.00	0.15	0.03	551	59.10	6.80	11.72	52.3	5348
114-150	Bt2	7.00	0.15	0.04	330	57.90	5.11	8.81	52.79	2410
150-200	Bt3	6.00	0.21	0.03	462	49.80	4.20	7.24	45.6	3234
	CV(%)	10.10	---	54.35	47	26.08	39.07	39.07	33.91	44.35
				Profile27						
0-12	AP	8.00	0.16	0.05	110	44.80	11.51	19.84	33.29	1588
12--52	AB	6.00	0.06	0.04	319	69.40	7.61	13.12	61.79	4049
52-117	Bt1	6.00	0.10	0.02	542	67.01	7.20	12.41	59.81	6505
117-158	Bt2	4.00	0.16	0.02	244	87.77	5.11	8.81	82.66	3122
158-200	Bt3	7.00	0.19	0.02	482	104.60	4.62	7.97	99.98	3182
	CV(%)	23.91	39.34	47.00	51.7	30.26	37.83	37.81	37.38	48.96

Cv = Coefficient of variation, Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation (Wilding, 1985) .

Appendix 3: Description of Soil Profiles Used for the Study

a) General site description

Soil mapping unit / pedon identifier	IM/OK/UM/CL01
Soil name	Umulolo Okigwe soil
Soil classification	Grossarenic Kandiudults (USDA), Chromic Acrisols (WRB)
Examination date	10/07/2010
Authors of description	Ahukaemere, C.M.
Location	Umulolo Okigwe (NIHORT) ($5^0 52^1 20.5^{11}$ N, $7^0 17^1 51.7^{11}$ E)
Elevation	152 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	garden egg, grasses – cultivated land
Micro relief	ridges

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
AP	0-9	Loamy sand, dark reddish brown (10 R 3/4) moist, moderate coarse sub- angular blocky, non sticky and non plastic (wet), very friable (moist) and soft (dry), many very fine (fibrous) roots, no faunal activity,clear smooth boundary, pH (H_2O) extremely acidic (4.32).
AB	9-26	Loamy sand, dark red (7.5 R 3/4) moist, moderate very coarse angular blocky, non sticky and non plastic (wet), friable moist and soft (dry), very few fine (fibrous) roots, no faunal activity, clear smooth boundary, pH (H_2O) stronly acidic (5.23)
Bt1	26-80	Loamy sand, dusky red (7.5 R 4/4) moist,, strong very coarse sub-angular blocky, non sticky and non plastic wet, firm moist and very hard dry, no root, no faunal activity, gradual smooth boundary, pH (H_2O) stronly acidic (5.11)
Bt2	80-103	Loamy sand, red (10 R 4/8) moist, strong very coarse angular blocky, slightly stick (wet), very firm (moist) and very hard (dry), no root, no fauna activity, diffused boundary, pH (H_2O) very stronly acidic (5.00)
Bt3	103-180	Loamy sand, red (10 R 5/8) moist, strong very coarse angular blocky, slightly sticky when wet, very firm (moist) and very hard (dry), no root, no fauna activity, pH (H_2O) very stronly acidic (4.9).

a) General site description

Soil mapping unit / pedon identifier	IM/OK/UM/CL02
Soil name	Umulolo Okigwe soil
Soil classification	Typic Kandiudults (USDA), Rhodic Acrisols (WRB)
Examination date	10/07/2010
Authors of description	Ahukaemere, C.M.
Location	Umulolo Okigwe (NIHORT) (5^0 52^1 18.2^{11} N, 7^0 17^1 49.6^{11} E)
Elevation	153 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	cassava, grasses – cultivated land
Micro relief	mounds

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
AP	0-9	Loamy sand, dark reddish brown (5 YR 3/3) moist, moderate fine granular, non sticky and non plastic (wet), very friable moist and soft (dry), many very fine (fibrous) roots, no fauna activity, clear smooth boundary, pH (H_2O) extremely acidic (4.43).
AB	9-29	Loamy sand, dark reddish brown (5 YR 3/6) moist, moderate coarse angular blocky, non sticky and non plastic (wet), friable moist and soft (dry), very few fine (fibrous) roots, no fauna activity, gradual smooth boundary, pH (H_2O) very strongly acidic (4.61).
Bt1	29-50	Loamy sand, dark red (7.5 Y 3/4) moist, moderate very coarse sub-angular blocky, non sticky and non plastic wet, firm moist and slightly hard, no roots, no fauna activity, diffused boundary, pH (H_2O) very strongly acidic (4.92).
Bt2	50-79	Sandy loam, red (10 R 5/8) moist, moderate very coarse sub-angular blocky, non sticky and non plastic wet, firm moist and slightly hard dry, no root, no fauna activity, diffused boundary, pH (H_2O) very strongly acidic (4.80).
Bt3	79-120	Sandy loam, red (10 R 6/6) moist, strong very coarse angular blocky, slightly Sticky (wet), very firm moist and very hard dry, no root, no fauna activity, diffused boundary, pH (H_2O) very strongly acidic (4.80).
Bt4	120-180	Sandy loam, reddish orange (10 R 6/8) moist, strong very coarse angular blocky, slightly sticky (wet), very firm (moist) and very hard (dry), no root, no fauna activity, pH (H_2O) very strongly acidic (4.70).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OK/UM/CL03
Soil name	Umulolo Okigwe soil
Soil classification	Grossarenic Kandiudults (USDA), Chromic Acrisols (WRB)
Examination date	10/07/2010
Authors of description	Ahukaemere, C.M
Location	Umulolo Okigwe (NIHORT) ($5^0 52^1 21.2^{11}$ N, $7^0 17^1 49.4^{11}$ E)
Elevation	150 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	garden egg, grasses – cultivated land
Micro relief	ridges.

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
AP	0-17	Loamy sand, dark reddish brown (5 YR 3/4) moist, moderate coarse sub-angular blocky, non sticky and non plastic (wet), very friable moist and soft (dry), many very fine (fibrous) roots, no fauna activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.00).
AB	17-29	Loamy sand, reddish brown (10 R 4/4) moist, moderate coarse sub-angular blocky, non sticky and non plastic (wet), friable moist and slightly hard (dry), very few fine (fibrous) roots, no fauna activity, diffused wavy boundary, pH (H_2O) very strongly acidic (4.50).
Bt1	29-46	Loamy sand, red (10 R 4/8) moist, moderate medium sub- angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard dry, no root, no fauna activity, diffused smooth boundary, pH (H_2O) very strongly acidic (4.60).
Bt2	46-98	Loamy sand, red (10 R 5/8) moist, strong coarse angular blocky, slightly sticky (wet), very firm moist and very hard (dry), no root, no fauna activity, diffused smooth boundary, pH (H_2O) very strongly acidic (4.60).
Bt3	98-178	Loamy sand, reddish orange (10 R 6/8) moist, strong very coarse angular blocky, slightly sticky (wet), very firm moist and very hard (dry), no root, no fauna activity, pH (H_2O) very strongly acidic (4.70).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OK/UM/SF04
Soil name	Umulolo Okigwe soil
Soil classification	Lithic Kanhapludults (USDA), Rhodic Acrisols (WRB)
Examination date	18/08/2010
Authors of description	Ahukaemere, C.M.
Location	Umulolo Okigwe (NIHORT) ($5^0\ 52^1\ 39.4^{11}$ N, $7^0\ 18^1\ 32.9^{11}$ E)
Elevation	154 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	< 1%
Climate	humid tropical
Vegetation/land use	scattered perennial trees and shrubs like oil been, oil palm – Secondary forest
Micro relief	termite mounds

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oe	0-1	Loamy sand, very dark reddish brown (5 YR 2/4) moist, moderate fine granular, non sticky and non plastic (wet), very friable moist and loose (dry), many coarse (secondary) roots, high faunal activity with partially decomposed organic materials, abrupt wavy boundary, pH (H_2O) very strongly acidic (4.51).
Oa	1-3	Loamy sand, 5 YR 2/4 moist, moderate medium granular, non sticky, very friable moist and soft (dry), many coarse pores, many coarse (secondary) roots, relatively high rooting and faunal activity, abrupt smooth boundary, pH (H_2O) extremely acidic (4.00).
A	3-9	Loamy sand, 5 YR 3/6 moist, moderate fine granular, non sticky and non plastic wet, friable moist and soft (dry) with many coarse pores, many coarse (secondary) roots, high faunal and rooting activity, clear smooth boundary, pH (H_2O) extremely acidic (4.20).
AB	9-40	Loamy sand, reddish brown (2.5 YR 4/6) moist, strong very coarse sub-angular, non sticky and non plastic wet, firm moist and hard dry, high rooting activity, many coarse (secondary) roots, high faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.10).
Bt1	40-89	Loamy sand, orange (2.5 YR 6/8) moist, strong medium angular, slightly sticky when wet, very firm (moist) and very hard (dry), presence of tap roots, no faunal activity, presence of gravel with diffused boundary, pH (H_2O) extremely acidic (4.10).
Bt2	89-160	Loamy sand, orange (2.5 YR 7/6) moist, strong medium sub-angular, slightly sticky when wet, very firm moist and very hard dry, presence of few tap roots, no faunal activity, presence of gravel (concretionary), pH (H_2O) extremely acidic (4.20).

a) General site description

Soil mapping unit / pedon identifier	IM/OK/UM/SF05
Soil name	Umulolo Okigwe soil
Soil classification	Grossarenic Kandiudults(USDA), Chromic Acrisols (WRB)
Examination date	18/08/2010
Authors of description	Ahukaemere, C.M.
Location	Umulolo Okigwe (NIHORT) ($5^0 52^1 42.6^{11}$ N, $7^0 18^1 52.7^{11}$ E)
Elevation	156 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	< 1%
Climate	humid tropical
Vegetation/land use	scattered perennial trees and shrubs, like oil been, oil palm – Secondary forest
Micro relief	termite mounds

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oe	0-2	Loamy sand, very dark brown (5 YR 4/8) moist, moderate fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many coarse (secondary) roots, high faunal activity with partially decomposed organic materials, abrupt smooth boundary, pH (H_2O) moderately acidic (5.90).
Oa	2-4	Loamy sand, dark reddish grey (2.5 YR 3/1) moist, moderate medium granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many coarse (secondary) roots, high faunal activity with partially decomposed organic materials, clear smooth boundary, pH (H_2O) very strongly acidic (4.20).
A	4-13	Loamy sand, dark reddish brown (2.5 YR 3/4) moist, moderate medium granular, non sticky and non plastic (wet), friable (moist) and soft (dry) with many coarse pores, many coarse (secondary) roots, high rooting and faunal activity with gradual smooth boundary, pH (H_2O) strongly acidic (5.30).
AB	13-49	sandy loam, bright brown (2.5 YR 4/8) moist, moderate medium Sub-angular blocky, non sticky and non plastic (wet), firm (moist) and hard (dry) with many coarse pores, few coarse (secondary) roots, high rooting and faunal activity with gradual smooth boundary, pH (H_2O) Very strongly acidic (5.00).

Bt1	49-91	loamy sand, orange (2.5 YR 6/6) moist, strong medium sub-angular blocky, slightly sticky (wet), very firm (moist) and very hard (dry), secondary roots with many tap roots, no faunal activity presence of gravels with diffused boundary, pH (H_2O) strongly acidic (5.10).
Bt2	91-158	sandy loam, orange (2.5YR 7/8) moist, moderate medium sub-angular blocky, slightly sticky (wet), very firm (moist) and very hard (dry), presence of few tap roots, no faunal activity, presence of gravel, pH (H_2O) strongly acidic (5.00).

a) General site description

Soil mapping unit / pedon identifier	IM/OK/UM/SF06
Soil name	Umulolo Okigwe soil
Soil classification	Lithic Kanhapludults (USDA), Rhodic Acrisols (WRB)
Examination date	18/08/2010
Authors of description	Ahukaemere, C.M
Location	Umulolo Okigwe (NIHORT) ($5^0\ 52^1\ 38.6^{11}$ N, $7^0\ 18^1\ 42.9^{11}$ E)
Elevation	154 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	< 1%
Climate	humid tropical
Vegetation/land use	scattered perennial trees and shrubs, like oil been, oil palm – Secondary forest
Micro relief	termite mounds

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oa	0-3	Loamy sand, dark reddish grey (2.5 YR 3/1) moist, moderate medium granular, non sticky and non plastic (wet), very friable (moist) and soft (dry), many medium and coarse (secondary) roots, high faunal activity with partially decomposed organic materials, clear smooth boundary, pH (H_2O) extremely acidic (4.20).
A	3-15	Sandy loam, dark reddish brown (2.5YR 3/4) moist, moderate medium granular, non sticky and non plastic (wet), friable (moist) and slightly hard (dry), few medium roots, high faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.21).
AB	15-60	Sandy loam, bright brown (2.5 YR 4/8) moist, strong coarse sub-angular blocky, non sticky and non plastic (wet), very firm (moist) and very hard (dry), few coarse roots, presence of gravels with diffused boundary, pH (H_2O) very strongly acidic (4.81).
Bt1	60-131	Sandy loam, orange (2.5YR 6/6) moist, strong medium sub- angular blocky, slightly sticky (wet), very firm (moist) and very hard (dry), few coarse roots and presence of tap roots , presence of gravels (concretionary / gravelly), pH (H_2O) very strongly acidic (4.71).

a) General site description

Soil mapping unit / pedon identifier	IM/OK/UM/FL07
Soil name	Umulolo Okigwe soil
Soil classification	Typic Kandiudults (USDA), Rhodic Acrisols (WRB)
Examination date	21/08/2010
Authors of description	Ahukaemere, C.M.
Location	Umulolo Okigwe (NIHORT) ($5^0 52^1 38.5^{11}$ N, $7^0 18^1 39.2^{11}$ E)
Elevation	147 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	grasses and shrubs, like elephant grass, chromolena odorata– fallow land
Micro relief	termite mounds

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
A	0-18	Loamy sand, reddish brown (5 YR 4/6) moist, moderate medium granular, non sticky and non plastic (wet), friable (moist) and slightly hard (dry), many fine (fibrous) and very few medium roots, little faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.20).
AB	18-49	Loamy sand, red (10 R 4/6) moist, moderate coarse angular blocky, non sticky and non plastic (wet), firm (moist) and hard (dry), many medium roots with very few fibrous roots, gradual smooth boundary, pH (H_2O) very strongly acidic (4.60).
Bt1	49-98	Loamy sand, red (10 R 4/8) moist, moderate coarse sub-angular blocky, slightly sticky and (wet), very firm (moist) and very hard (dry), few medium roots and gradual smooth boundary, pH (H_2O) very strongly acidic (4.70).
Bt2	98-145	Loamy sand, red (10 R 5/8) moist, moderate coarse sub-angular blocky, slightly sticky and (wet), very firm (moist) and extremely hard (dry) with very few medium roots, pH (H_2O) very strongly acidic (4.70). .

a) General site description

Soil mapping unit / pedon identifier	IM/OK/UM/FL08
Soil name	Umulolo Okigwe soil
Soil classification	Arenic Kandiudults (USDA), Chromic Acrisols (WRB)
Examination date	21/08/2010
Authors of description	Ahukaemere, C.M.
Location	Umulolo Okigwe (NIHORT) ($5^0 52^1 38.1^{11}$ N, $7^0 18^1 37.2^{11}$ E)
Elevation	146 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	grasses and shrubs, like elephant grass, chromolena odorata–fallow land
Micro relief	termite mounds

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
A	0-9	Loamy sand, reddish brown (5 YR 4/6) moist, moderate medium Sub-granular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), many fine (fibrous) and very few medium roots, little faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.10).
AB	9-35	Sandy loam, red (10 R 4/6) moist, moderate medium Sub-granular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), many medium roots, little faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.20).
Bt1	35-76	Loamy sand, red (10 R 4/8) moist, moderate medium Sub-granular blocky, non sticky and non plastic (wet), very firm (moist) and hard (dry), few medium roots, little faunal activity, clear wavy boundary, pH (H_2O) extremely acidic (4.30).
Bt2	76-140	Loamy sand, red (10 R 5/8) moist, moderate medium Sub-granular blocky, slightly sticky and non plastic (wet), very firm (moist) and hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.40).

a) General site description

Soil mapping unit / pedon identifier	IM/OK/UM/FL09
Soil name	Umulolo Okigwe soil
Soil classification	Typic Kandiudults (USDA), Rhodic Acrisol (WRB)
Examination date	21/08/2010
Authors of description	Ahukaemere, C.M.
Location	Umulolo Okigwe (NIHORT) (5^{0} 52^{1} 48.1^{11} N, 7^{0} 18^{1} 27.2^{11} E)
Elevation	145 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	grasses and shrubs, like elephant grass, chromolena odorata– fallow land
Micro relief	termite mounds

b) General information on soil

Parent material	Falsebedded sandstone
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
A	0-15	Loamy sand, dark reddish brown (5 YR 3/6) moist, moderate very fine granular, non sticky and non plastic (wet), friable (moist) and soft (dry), many very fine (fibrous) and very few medium roots, little faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.10).
AB	15-33	Loamy sand, reddish brown (5 YR 4/6) moist, moderate very coarse angular blocky, non sticky and non plastic (wet), firm (moist) and hard (dry), few fine (fibrous) and many medium roots, no faunal activity, gradual wavy boundary, pH (H_2O) extremely acidic (4.00).
Bt1	33-98	Loamy sand, reddish brown (2.5 YR 4/8) moist, strong coarse Sub-granular blocky, non sticky and non plastic (wet), very firm (moist) and hard (dry), very few medium roots, no faunal activity, diffuse boundary, pH (H_2O) extremely acidic (4.30).
Bt2	98-130	Loamy sand, red (10 YR 4/6) moist, strong very coarse Sub-granular blocky, non sticky and non plastic (wet), very firm (moist) and hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.30).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/SF010
Soil name	Itumbuzor soil
Soil classification	Vertic Paleudults (USDA), Haplic Acrisols (WRB)
Examination date	04/09/2010
Authors of description	Ahukaemere, C.M.
Location	Itumbuzor ($5^0\ 50^1\ 37.5^{11}$ N, $7^0\ 68^1\ 04.2^{11}$ E)
Elevation	140m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.5%
Climate	humid tropical
Vegetation/land use	trees, shrubs and some grasses – secondary forest
Micro relief	ant hills and cabitermes termite mounds

b) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	well drained – imperfectly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oa	0-5	Sandy loam, dark reddish brown (2.5 YR 3/3) moist, moderate fine granular, non sticky and non plastic (wet)friable (moist) and soft (dry), very few medium and coarse roots, high faunal activity, clear smooth boundary, pH (H_2O) slightly acidic (6.20).
A	5-19	Loam, brown (7.5 YR 4/6) moist, moderate fine granular, non sticky and non plastic (wet)friable (moist) and soft (dry), very few coarse roots, high faunal activity, clear smooth boundary, pH (H_2O) moderately acidic (5.70).
AB	19-56	Clay Loam, dark reddish brown (5 YR 3/6) moist, moderate medium sub- angular, sticky and slightly plastic (wet), firm (moist) and hard (dry), few coarse roots, little faunal activity, gradual smooth boundary, pH (H_2O) very strongly acidic (4.80).
Bt1	56-98	Silt clay Loam, dark red (10 R 4/6) moist, moderate medium sub-angular, sticky and slightly plastic (wet), very firm (moist) and hard (dry), very few coarse roots, no faunal activity, gradual smooth boundary, pH (H_2O) very strongly acidic (4.60).
Bt2	98-142	Silt clay Loam, red (10 R 4/8) moist, moderate very coarse angular, very sticky and very plastic (wet), very firm (moist) and very hard (dry), very few coarse roots, no faunal activity, diffuse boundary, pH (H_2O) very strongly acidic (4.50).
Bss	142-189	Silt clay , reddish brown (10 R 5/3) moist, moderate very coarse angular, imperfectly drained, very sticky and very plastic (wet), presence of slickensides, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.50).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/SF011
Soil name	Itumbuzor soil
Soil classification	Vertic Paleudults (USDA), Haplic Acrisols (WRB)
Examination date	04/09/2010
Authors of description	Ahukaemere, C.M.
Location	Itumbuzor ($5^0\ 53^1\ 28.5^{11}$ N, $7^0\ 18^1\ 39.2^{11}$ E)
Elevation	153m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.5%
Climate	humid tropical
Vegetation/land use	trees, shrubs and some grasses –secondary forest
Micro relief	Ant hills and nasute termite mounds

b) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	Imperfectly - poorly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oa	0-3	Loam, very dark brown (7.5 YR 2/3) moist, weak, very fine granular, non sticky and non plastic (wet) friable (moist) and soft (dry), very few medium and few coarse roots, high faunal activity, clear smooth boundary, pH (H_2O) moderately acidic (5.60).
A	3-10	Loam, dark reddish brown (5 YR 3/4) moist, moderate very fine granular, non sticky and non plastic (wet) firm (moist) and soft (dry), very few medium and coarse roots, high faunal activity, clear wavy boundary, pH (H_2O) moderately acidic (5.50).
AB	10-36	silt clay Loam, grayish red (10 R 4/2) moist, weak very fine sub-Angular blocky, sticky and slightly plastic (wet), firm (moist) and hard (dry), few coarse roots, no faunal activity, gradual smooth boundary, pH (H_2O) strongly acidic (5.30).
Bt1	36-60	Silt clay, grayish red (10 R 4/2) moist, moderate medium sub- angular blocky, sticky and slightly plastic (wet), firm (moist) and hard (dry), very few coarse roots, no faunal activity, gradual smooth boundary, pH (H_2O) strongly acidic (5.2).
Bt2	60-110	Silt clay, dark red (7.5 YR 4/4) moist, strong coarse Angular blocky, very sticky and very plastic (wet), very firm (moist) and very hard (dry), very few coarse roots, no faunal activity, diffuse boundary, pH (H_2O) very strongly acidic (4.90).
Bss	110-185	Clay , red (10 R 5/8) moist, moderate very coarse sub-angular blocky, very sticky and very plastic (wet), with slickensides, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) very strongly acidic (4.80).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/SF012
Soil name	Itumbuzor soil
Soil classification	Vertic Paleudults (USDA), Haplic Acrisols (WRB)
Examination date	04/09/2010
Authors of description	Ahukaemere, C.M
Location	Itumbuzor (5^0 50^1 37.5^{11} N, 7^0 68^1 04.2^{11} E)
Elevation	141m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.2%
Climate	humid tropical
Vegetation/land use	trees, shrubs and some grasses – secondary forest
Micro relief	Ant hills and nasute termite mounds

b) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	poorly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oa	0-3	Loam, dark reddish brown (2.5 YR 5/8) moist, moderate fine granular, non sticky and non plastic (wet), friable (moist) and soft (dry), many medium and few coarse woody roots, high faunal activity, clear smooth boundary, pH (H_2O) moderately acidic (5.70).
A	3-14	Loam, dark brown (7.5 YR 3/4) moist, weak fine granular, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), very few medium and coarse roots, high faunal activity, clear smooth boundary, pH (H_2O) moderately acidic (5.70).
AB	14-50	Silt clay Loam, dusky red (7.5 YR 6/6) moist, moderate fine sub-angular blocky, sticky and slightly plastic (wet), firm (moist) and hard (dry), few coarse roots, no faunal activity, gradual smooth boundary, pH (H_2O) moderately acidic (5.60).
Bt1	50-89	Silt clay loam, dull reddish brown (5 YR 4/2) moist, moderate medium angular blocky, sticky and plastic (wet), firm (moist) and hard (dry), very few coarse woody roots, no faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.50).
Bt2	89-107	Clay, red (7.5 YR 4/8) moist, moderate medium sub-angular blocky, very sticky and plastic (wet), very firm (moist) and very hard (dry), very few coarse woody roots, no faunal activity, diffuse boundary, pH (H_2O) extremely acidic (4.40).
Bss	107-189	Clay ,dark red (10 R 3/4) moist, moderate very coarse sub-angular blocky, very sticky and plastic (wet) with slickensides, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.30).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/CL013
Soil name	Itumbuzor soil
Soil classification	Vertic Paleudults (USDA), Haplic Acrisols (WRB)
Examination date	10/09/2010
Authors of description	Ahukaemere, C.M
Location	Itumbuzor (5^0 55^1 39.5^{11} N, 7^0 69^1 07.2^{11} E)
Elevation	142m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.2%
Climate	humid tropical
Vegetation/land use	cassava, maize and yam – cultivated land
Micro relief	cassava and yam mounds

c) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	poorly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

d) Profile description

Horizon	Depth (cm)	Description
AP	0-12	Sandy loam, very dark reddish brown (2.5 YR 2/2) moist, moderate fine granular, non sticky and non plastic, friable (moist) and soft (dry), many fibrous roots, no faunal activity with clear smooth boundary, pH (H_2O) every strongly acidic (4.60).
AB	12-66	Sandy clay loam, reddish brown (10 R 4/4) moist, moderate fine granular, non sticky and non plastic, firm (moist) and hard (dry), few fibrous roots, no faunal activity with gradual smooth boundary, pH (H_2O) extremely acidic (4.50).
Bt1	66-104	Silt clay loam, brownish gray (5 Y 6/2) moist, moderate fine Sub-angular, sticky and plastic, firm (moist) and hard (dry), no root, no faunal activity with gradual wavy boundary, pH (H_2O) extremely acidic (4.30).
Bt2	104-143	clay, reddish brown (5 YR 4/6) moist, moderate medium Sub-angular, very sticky and plastic, very firm (moist) and very hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.20).
Bss	143-180	clay, brownish gray (5 YR 6/1) moist, moderate medium angular, presence of slickensides, very sticky and plastic, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.10).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/CL014
Soil name	Itumbuzor soil
Soil classification	Vertic Paleudults (USDA), Chromic Acrisols (WRB).
Examination date	10/09/2010
Authors of description	Ahukaemere, C.M.
Location	Itumbuzor ($5^0\ 54^1\ 39.5^{11}$ N, $7^0\ 69^1\ 07.2^{11}$ E)
Elevation	142m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.2%
Climate	humid tropical
Vegetation/land use	grasses, maize plant, cassava, yam – cultivated land
Micro relief	ridges, old yam mounds

b) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	poorly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

d) Profile description

Horizon	Depth (cm)	Description
AP	0-9	Sandy loam, grayish red (10 R 4/2) moist, moderate very fine granular, non sticky and non plastic, friable (moist) and soft (dry), many very fine roots, no faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.20).
AB	9-70	Loam, reddish brown (7.5 R 4/2) moist, moderate fine granular, non sticky and non plastic, firm (moist) and hard (dry), few fibrous roots, no faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.30).
Bt1	70-89	Silty clay loam, light olive gray (5 Y 6/2) moist, moderate coarse Sub-angular blocky, sticky and plastic, firm (moist) and hard (dry), no roots, no faunal activity with gradual smooth boundary, pH (H_2O) extremely acidic (4.20).
Bt2	89-117	Clay, dull reddish brown (7.5 YR 4/6) moist, moderate very coarse Sub-angular, very sticky and plastic, very firm (moist) and very hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.30).
Bss	117-180	Clay, brownish red (7.5 R 4/6) moist, moderate very coarse sub-angular, very sticky and plastic with slickensides, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.10).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/CL015
Soil name	Itumbuzor soil
Soil classification	Vertic Paleudults (USDA), Chromic Acrisols (WRB).
Examination date	10/09/2010
Authors of description	Ahukaemere, C.M.
Location	Itumbuzor ($5^0 52^1 38.5^{11}$ N, $7^0 28^1 39.2^{11}$ E)
Elevation	140m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.2%
Climate	humid tropical
Vegetation/land use	grasses, yam, cassava – cultivated land
Micro relief	nil

b) General information on soil

Parent material	Shale (Bende Amaki group)
Moisture status	moist
Drainage status	poorly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

b) Profile description

Horizon	Depth (cm)	Description
AP	0-9	Sandy loam, dark reddish brown (2.5 YR 3/4) moist, moderate very fine granular, non sticky and non plastic, friable (moist) and soft (dry), many fibrous roots, no faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.20).
AB	9-68	Sandy clay Loam, dusky red (7.5 R 4/4) moist, moderate fine granular, non sticky and non plastic, firm (moist) and hard (dry), few fibrous roots, no faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.50).
Bt1	68-105	Silty clay, reddish brown (10 R 5/3) moist, moderate coarse angular, slightly sticky and plastic, firm (moist) and hard (dry), no roots, no faunal activity with gradual smooth boundary, pH (H_2O) very strongly acidic (4.60).
Bt2	105-133	Silty clay, dark reddish brown (2.5 YR 3/4) moist, moderate very coarse angular, very sticky and plastic, very firm (moist) and very hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.20).
Bss	133-185	Clay, reddish brown (10 R 4/4) moist, moderate very coarse sub-angular, very sticky and plastic, with slickensides, very firm (moist) and extremely hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.00).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/FL016
Soil name	Itumbuzor soil
Soil classification	Entic Paleudults (USDA), Haplic Acrisols (WRB)
Examination date	14/09/2010
Authors of description	Ahukaemere, C.M.
Location	Itumbuzor ($5^0 42^1 38.5^{11}$ N, $7^0 18^1 39.2^{11}$ E)
Elevation	140m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.2%
Climate	humid tropical
Vegetation/land use	grasses, shrubs, wild legumes – fallow land
Micro relief	nil

b) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	poorly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

b) Profile description

Horizon	Depth (cm)	Description
A	0-14	Sandy loam, dark reddish brown (5 YR 3/4) moist, weak very fine granular, non sticky and non plastic, friable (moist) and soft (dry), many fine and few medium roots, little faunal activity, clear wavy boundary, pH (H_2O) extremely acidic (4.00).
AB	14-37	Loam, reddish brown (10 R 5/3) moist, weak, medium sub-angular blocky non sticky and non plastic, firm (moist) and slightly hard (dry), many medium roots, no faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.10).
Bt1	37-58	Clay loam, light olive gray (5 Y 5/3) moist, moderate medium sub-angular blocky, sticky and plastic, firm (moist) and hard (dry), few medium roots, no faunal activity with clear wavy boundary, pH (H_2O) extremely acidic (4.10).
Bt2	58-100	Silt clay loam, dull reddish brown (7.5 R 4/2) moist, moderate medium sub- angular, very sticky and plastic, very firm (moist) and very hard (dry), very few coarse roots, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.20).
Bt3	100-148	Silty clay, bright reddish brown (10 R 4/4) moist, moderate very coarse sub- angular, very sticky and plastic, very firm (moist) and very hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.30).
Bt4	148-186	Clay, reddish brown (10 R 5/4) moist, moderate very coarse sub- angular, very sticky and plastic, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.10).

a) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/FL017
Soil name	Itumbuzor soil
Soil classification	Entic Paleudults (USDA), Haplic Acrisols (WRB).
Examination date	14/09/2010
Authors of description	Ahukaemere, C.M.
Location	Itumbuzor ($5^0 52^1 38.5^{11}$ N, $7^0 18^1 39.2^{11}$ E)
Elevation	142m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.2%
Climate	humid tropical
Vegetation/land use	grasses, shrubs, wild legumes – fallow land
Micro relief	cubitermes termite mounds

b) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	Well drained -Imperfectly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

b) Profile description

Horizon	Depth (cm)	Description
A	0-12	Sandy loam, dark brown (7.5 YR 3/2) moist, weak fine granular, non sticky and non plastic, friable (moist) and soft (dry), many fibrous and few medium woody roots, little faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.20).
AB	12-38	Loam, dark reddish brown (7.5 R 2/3) moist, weak, medium sub-angular blocky non sticky and non plastic, firm (moist) and slightly hard (dry), many medium woody roots, little faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.30).
Bt1	38-57	Silty clay, grayish red (2.5 YR 4/2) moist, moderate medium sub-angular blocky, sticky and plastic, firm (moist) and hard (dry), few medium woody roots, no faunal activity with diffused boundary, pH (H_2O) extremely acidic (4.40).
Bt2	57-145	Clay loam, dark reddish brown (2.5 YR 3/6) moist, moderate medium sub- angular, very sticky and plastic, very firm (moist) and very hard (dry), very few coarse roots, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.30).
Bt3	145-185	Clay loam, bright brown (2.5 YR 5/6) moist, strong very coarse sub- angular blocky, very sticky and plastic, imperfectly drained, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.40).

c) General site description

Soil mapping unit / pedon identifier	AB/IT/AU/FL018
Soil name	Itumbuzor soil
Soil classification	Entic Paleudults (USDA), Haplic Acrisols (WRB)
Examination date	03/08/2010
Authors of description	Ahukaemere, C.M.
Location	Itumbuzor ($5^0 52^1 38.5^{11}$ N, $7^0 18^1 39.2^{11}$ E)
Elevation	140m
Land form	valley (slightly)
Age of erosion/geomorphic surface	very slight sheet erosion/gently sloping
Topography of land form	slightly hilly to undulating
Micro topography (slope)	1.5%
Climate	humid tropical
Vegetation/land use	grasses, shrubs, wild legumes – fallow land
Micro relief	cubitermes termite mounds

b) General information on soil

Parent material	Shale (Bende Ameki group)
Moisture status	moist
Drainage status	Well drained - Imperfectly drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
A	0-11	Sandy loam, dark reddish brown (5 YR 3/2) moist, moderate medium granular, non sticky and non plastic, friable (moist) and soft (dry), well drained, many fibrous and medium woody roots, little faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.40).
AB	11-44	Loam, grayish red (10.5 R 4/2) moist, moderate, medium sub-angular blocky, non sticky and non plastic, firm (moist) and hard (dry), imperfectly drained, few medium roots, no faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.30).
Bt1	44-95	Silty clay loam, reddish brown (2.5 YR 2/6) moist, moderate medium sub-angular blocky, sticky and plastic, very firm (moist) and very hard (dry), few medium woody roots, no faunal activity, diffused boundary, pH (H_2O) extremely acidic (4.40).
Bt2	95-123	Clay, bright reddish brown (5 YR 5/6) moist, strong coarse angular blocky, very sticky and plastic, very firm (moist) and very hard (dry), very few tap roots, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.20).
Bt3	123-180	Clay, orange (2.5 YR 6/6) moist, strong coarse angular blocky, very sticky and plastic, Imperfectly drained, very firm (moist) and very hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.30).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OH/UM/SF019
Soil name	**U**muagwo soil
Soil classification	Arenic paleudults (USDA), Chromic Acrisols (WRB)
Examination date	25/09/2010
Authors of description	Ahukaemere, C.M
Location	Umuagwo, Ohaji (Imo poly) ($5^0 19^1 29.4^{11}$ N, $6^0 58^1 32.6^{11}$ E)
Elevation	61 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	< 1%
Climate	humid tropical
Vegetation/land use	scattered perennial trees and shrubs like oil been, oil palm – secondary forest
Micro relief	termite mounds, ant hills

d) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

e) Profile description

Horizon	Depth (cm)	Description
Oe	0-4	Loamy sand, dark reddish gray (7.5 R 3/1) moist, weak very fine granular, non sticky and non plastic (wet), very friable moist and loose (dry), many medium and coarse roots, high faunal activity with partially decomposed organic materials, abrupt wavy boundary, pH (H_2O) very strongly acidic (5.01).
Oa	4-18	Loamy sand, dark brown (10 YR 3/3) moist, moderate very fine granular, non sticky and non plastic (wet), very friable moist and soft (dry), many coarse pores, many medium and coarse roots, relatively high rooting and faunal activity, abrupt smooth boundary, pH (H_2O) very strongly acidic (4.78).
A	18-48	Loamy sand, brown (7.5 YR 4/3) moist, moderate fine granular, non sticky and non plastic wet, very friable moist and soft (dry) with many coarse pores, many coarse roots, high faunal and rooting activity, clear smooth boundary, pH (H_2O) extremely acidic (4.35).
AB	48-99	Sandy loam, brown (7.5 YR 4/4) moist, moderate medium sub-angula,r non sticky and non plastic, friable (moist) and soft (dry), high rooting activity, very few coarse roots, no faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.20).
Bt1	99-154	sandy loam, strong brown (7.5 YR 5/8) moist, moderate fine granular, non sticky and non plastic , friable (moist) and soft (dry), presence of tap roots, no faunal activity, diffused boundary, pH (H_2O) extremely acidic (4.20).
Bt2	154-200	sandy loam, red (2.5 YR 5/8) moist, strong medium angular blocky, non sticky and non plastic, firm (moist) and hard (dry), presence of few tap roots, pH (H_2O) very strongly acidic (4.80).

a) General soil profile description

Soil mapping unit / pedon identifier IM/OH/UM/SF020

Soil name	**U**muagwo soil
Soil classification	Arenic paleudults (USDA), Chromic Acrisols (WRB)
Examination date	25/09/2010
Authors of description	Ahukaemere, C.M.
Location	Umuagwo, Ohaji (Imo poly) ($5^0\,19^1\,29.4^{11}$ N, $6^0\,58^1\,32.6^{11}$ E)
Elevation	61 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	scattered perennial trees and shrubs like oil been, oil palm – secondary forest
Micro relief	termite mounds, ant hills

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oe	0-5	Loamy sand, very dark gray (7.5 YR 3/1) moist, weak very fine granular, non sticky and non plastic (wet), very friable moist and loose (dry), many medium and coarse roots, high faunal activity with partially decomposed organic materials, clear smooth boundary, pH (H_2O) extremely acidic (4.49).
Oa	5-18	Loamy sand, dark gray (7.5 YR 4/1) moist, moderate fine granular, non sticky and non plastic (wet), very friable (moist) and soft (dry), many coarse pores, few fine and many medium and roots, high rooting and faunal activity, clear smooth boundary, pH (H_2O) extremely acidic (4.36).
A	18-47	Loamy sand, reddish brown (5 YR 5/4) moist, moderate fine granular, non sticky and non plastic wet, friable (moist) and soft (dry) with many coarse pores, very few coarse roots, high faunal and rooting activity, clear smooth boundary, pH (H_2O) extremely acidic (4.31).
AB	47-107	Sandy loam, strong brown (7.5 YR 5/6) moist, moderate medium granular non sticky and non plastic, friable (moist) and soft (dry), very few coarse roots, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.26).
Bt1	107-142	sandy loam, strong brown (7.5 YR 5/6) moist, moderate medium sub-angular blocky, non sticky and non plastic , firm (moist) and soft (dry), presence of tap roots, no faunal activity, diffused boundary, pH (H_2O) very strongly acidic (5.18).
Bt2	142-200	sandy loam, yellowish red (5 YR 5/6) moist, moderate medium sub-angular blocky, non sticky and non plastic, firm (moist) and hard (dry), no root, no faunal activity, pH (H_2O) extremely acidic (4.40).

a) General soil profile description

Soil mapping unit / pedon identifier IM/OH/UM/SF021

Soil name	**U**muagwo soil
Soil classification	Arenic paleudults (USDA), Chromic Acrisols (WRB)
Examination date	25/09/2010
Authors of description	Ahukaemere, C.M.
Location	Umuagwo, Ohaji (Imo poly) (5^0 19^1 20.4^{11} N, 6^0 28^1 32.6^{11} E)
Elevation	62 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	< 1%
Climate	humid tropical
Vegetation/land use	scattered perennial trees and shrubs like Gmelina arborea oil palm – secondary forest
Micro relief	termite mounds, ant hills

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Oe	0-3	Loamy sand, dark reddish brown (2.5 YR 5/4) moist, moderate medium granular, non sticky and non plastic (wet), very friable moist and loose (dry), many medium and coarse roots, high faunal activity with partially decomposed organic materials, clear smooth boundary, pH (H_2O) very strongly acidic (5.01).
Oa	3-21	Loamy sand, dark reddish brown (5 YR 3/2) moist, moderate fine granular, non sticky and non plastic (wet), very friable (moist) and soft (dry), many coarse pores, many medium and few coarse roots, high rooting and faunal activity, clear smooth boundary, pH (H_2O) moderately acidic (5.76).
A	21-48	Loamy sand, reddish yellow (7.5 YR 6/6) moist, moderate very fine granular, non sticky and non plastic wet, friable (moist) and soft (dry) with many coarse pores, few medium roots, high faunal activity, clear smooth boundary,
AB	48-103	Sandy loam, reddish brown (2.5 YR 4/) moist, moderate very fine granular non sticky and non plastic, firm (moist) and slightly hard (dry), very few medium roots, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.44).
Bt1	103-150	sandy loam, yellowish red (5 YR 5/8) moist, moderate fine granular non sticky and non plastic , firm (moist) and soft (dry), presence of few tap roots, no faunal activity, diffused boundary, pH (H_2O) very strongly acidic (5.35).
Bt2	150-200	sandy loam, light red (2.5 YR 6/8) moist, moderate fine granular, non sticky and non plastic, firm (moist) and slightly hard (dry), no root, no faunal activity, pH (H_2O) very strongly acidic (4.90).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OH/UM/FL022
Soil name	**U**muagwo soil
Soil classification	Typic Hapludults (USDA), Arenic Acrisols (WRB)
Examination date	25/09/2010
Authors of description	Ahukaemere, C.M.
Location	Umuagwo, Ohaji (Imo poly) (5^0 29^1 40.4^{11} N, 6^0 34^1 32.6^{11} E)
Elevation	63 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	grasses and shrubs such as elephant grass, goat weed – fallow
Micro relief	macro termite mounds

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
A	0-11	Loamy sand, dark reddish brown (5 YR 3/4) moist, moderate very fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), few fine roots, no faunal activity clear smooth boundary, pH (H_2O) extremely acidic (4.17).
AB	11-31	Sand, dark reddish gray (5 YR 4/2) moist, moderate very fine granular, non sticky and non plastic (wet), very friable (moist) and soft (dry), many medium roots, no faunal activity gradual smooth boundary, pH (H_2O) extremely acidic (4.45).
Bt1	31-86	Loamy sand, weak red (2.5 YR 4/2) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), friable (moist) and slightly hard (dry), many medium roots, no faunal activity diffused lower boundary, pH (H_2O) moderately acidic (6.03)
Bt2	86-121	Loamy sand, red (2.5 YR 4/8) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), very few medium roots, no faunal activity diffused lower boundary, pH (H_2O) strongly acidic (5.30).
Bt3	121-154	Loamy sand, red (2.5 YR 4/8) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), no root, no faunal activity diffused lower boundary, pH (H_2O) strongly acidic (5.02).
Bt4	154-200	Loamy sand, yellowish red (5 YR 5/8) moist, moderate very coarse angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), no root, no faunal activity, pH (H_2O) strongly acidic (5.11).

a) General soil profile description

Soil mapping unit / pedon identifier IM/OH/UM/FL023

Soil name	**U**muagwo Ohaji Egbema soil
Soil classification	Psammentic Hapludults (USDA), Arenic Acrisols (WRB)
Examination date	30/09/2010
Authors of description	Ahukaemere, C.M.
Location	Umuagwo (Imo poly) ($5^0 29^1 40.4^{11}$ N, $6^0 38^1 32.6^{11}$ E)
Elevation	63 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	grasses and shrubs such as Chromolena odorata, goat weed – fallow land
Micro relief	cubitermes termite mounds, ant hills

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
A	0-15	Sand, dark reddish brown (5 YR 3/2) moist, weak very fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many fine roots, no faunal activity clear smooth boundary, pH (H_2O) extremely acidic (4.47).
AB	15-58	Sand, dark reddish brown (5 YR 3/4) moist, weak very fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many fine roots, no faunal activity gradual smooth boundary, pH (H_2O) extremely acidic (4.42).
Bt1	58-105	Loamy sand, reddish brown (5 YR 4/4) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), friable (moist) and soft (dry), very few medium roots, no faunal activity, diffused lower boundary, pH (H_2O) very strongly acidic (4.81).
Bt2	105-150	Sandy loam, reddish brown (5 YR 4/4) moist, moderate coarse angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), very few secondary woody roots, no faunal activity diffused lower boundary, pH (H_2O) very strongly acidic (4.55).
Bt3	150-200	Sandy loam, red (2.5 YR 5/8) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), no root, no faunal activity, pH (H_2O) very strongly acidic (4.88).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OH/UM/FL024
Soil name	**U**muagwo soil
Soil classification	Arenic Paleudults (USDA), Arenic Acrisols (WRB)
Examination date	30/09/2010
Authors of description	Ahukaemere, C.M.
Location	Umuagwo, Ohaji (Imo poly) (5^0 19^1 20.4^{11} N, 6^0 28^1 32.6^{11} E)
Elevation	63 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	grasses and shrubs – fallow land
Micro relief	cubitermes termite mounds, ant hills

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
Ap	0-20	Loamy sand, reddish brown (5 YR 5/2) moist, moderate fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many very fine roots, no faunal activity clear smooth boundary, pH (H_2O) strongly acidic (5.47).
AB	20-48	Loamy sand, strong brown (7.5 YR 4/6) moist, moderate coarse sub-angular, non sticky and non plastic (wet), friable (moist) and soft (dry), no roots, no faunal activity clear smooth boundary, pH (H_2O) strongly acidic (5.42).
Bt1	48-110	Sandy loam, yellowish brown (5 YR 5/6) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), friable (moist) and slightly hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) very strongly acidic (4.89).
Bt2	110-152	Sandy loam, light red (2.5 YR 6/8) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) very strongly acidic (4.95).
Bt3	152-200	Sandy loam, yellowish red (5 YR 5/6) moist, moderate coarse sub-angular blocky, non sticky and non plastic (wet), firm (moist) and hard (dry), no root, no faunal activity, pH (H_2O) moderately acidic (4.81).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OH/UM/CL025
Soil name	**U**muagwo soil
Soil classification	Typic Hapludults (USDA), Arenic Acrisol (WRB).
Examination date	30/09/2010
Authors of description	Ahukaemere, C.M.
Location	Umuagwo, Ohaji (Imo poly) ($5^0 21^1 29.4^{11}$ N, $6^0 32^1 41.6^{11}$ E)
Elevation	62 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	1%
Climate	humid tropical
Vegetation/land use	grasses, egg plant, hot and green pepper – cultivated land
Micro relief	ridges

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
AP	0-20	Loamy sand, reddish brown (5 YR 5/2) moist, moderate fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many fine roots, no faunal activity clear smooth boundary, pH (H_2O) strongly acidic (5.52).
AB	20-48	Loamy sand, strong brown (7.5 YR 4/6) moist, moderate medium Sub-angular blocky, non sticky and non plastic (wet), friable (moist) and soft (dry), no root, no faunal activity gradual smooth boundary, pH (H_2O) strongly acidic (5.13).
Bt1	48-110	Sandy loam, yellowish red (5 YR 5/6) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), friable (moist) and slightly hard (dry), no root, no faunal activity, gradual wavy boundary, pH (H_2O) moderately acidic (5.67).
Bt2	110-152	Sandy loam, light red (2.5 YR 6/8) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) extremely acidic (4.46).
Bt3	152-200	Sandy loam, yellowish red (5 YR 5/6) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and hard (dry), no root, no faunal activity. pH (H_2O) extremely acidic (4.40).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OH/UM/CL026
Soil name	**U**muagwo soil
Soil classification	Typic Hapludults (USDA), Arenic Acrisols (WRB).
Examination date	30/09/2010
Authors of description	Ahukaemere, C.M
Location	Umuagwo Ohaji (Imo poly) ($5^0 19^1 20.4^{11}$ N, $6^0 28^1 32.6^{11}$ E)
Elevation	61 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	< 1%
Climate	humid tropical
Vegetation/land use	grasses, Telferia, okra, maize plant – cultivated land
Micro relief	ridges

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
AP	0-28	Loamy sand, reddish brown (5 YR 3/3) moist, moderate fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many fine roots, no faunal activity clear smooth boundary, pH (H_2O) very strongly acidic (4.91).
AB	28-49	Loamy sand, yellowish red (5 YR 5/6) moist, moderate medium granular, non sticky and non plastic (wet), friable (moist) and soft (dry), no roots, no faunal activity gradual smooth boundary, pH (H_2O) very strongly acidic (4.64).
Bt1	49-114	Loamy sand, brown (7.5 YR 4/4) moist, moderate coarse angular blocky, non sticky and non plastic (wet), friable (moist) and slightly hard (dry), no root, no faunal activity, gradual smooth boundary, pH (H_2O) extremely acidic (4.18).
Bt2	114-150	Sandy loam, yellowish red (5 YR 4/6) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) very strongly acidic (4.90).
Bt3	150-200	Sandy loam, red (10R 5/8) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and hard (dry), no roots, no faunal activity, pH (H_2O) extremely acidic (4.50).

a) General soil profile description

Soil mapping unit / pedon identifier	IM/OH/UM/CL027
Soil name	**U**muagwo soil
Soil classification	Typic Hapludults (USDA), Arenic Acrisols (WRB).
Examination date	30/09/2010
Authors of description	Ahukaemere, C.M.
Location	Umuagwo, Ohaji (Imo poly)($5^0\,19^1\,20.4^{11}$ N, $6^0\,28^1\,32.6^{11}$ E)
Elevation	61 m
Land form	plain
Age of erosion/geomorphic surface	not discernible
Topography of land form	flat
Micro topography (slope)	< 1%
Climate	humid tropical
Vegetation/land use	grasses, okra, pepper – cultivated land
Micro relief	ridges

b) General information on soil

Parent material	Coastal plain sand
Moisture status	moist
Drainage status	well drained
Depth of water table	not encountered
Surface stoniness	nil
Rock out crop	nil

c) Profile description

Horizon	Depth (cm)	Description
AP	0-12	Sand, dark reddish brown (5 YR 3/2) moist, weak fine granular, non sticky and non plastic (wet), very friable (moist) and loose (dry), many fine roots, no faunal activity, clear smooth boundary, pH (H_2O) very strongly acidic (5.51).
AB	12-52	Loamy sand, reddish brown (5 YR 5/4) moist, moderate coarse angular blocky, non sticky and non plastic (wet), friable (moist) and soft (dry), no root, no faunal activity gradual smooth boundary, pH (H_2O) very strongly acidic (5.23).
Bt1	52-117	sandy loam, red (2.5 YR 4/6) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), friable (moist) and soft (dry), no root, no faunal activity, gradual smooth boundary, pH (H_2O) moderately acidic (5.67).
Bt2	117-158	Sandy loam, light red (2.5 YR 6/8) moist, moderate medium sub-angular blocky, non sticky and non plastic (wet), firm (moist) and slightly hard (dry), no root, no faunal activity, diffused lower boundary, pH (H_2O) very strongly acidic (4.56).
Bt3	158-200	Sandy loam, red (2.5 YR 5/8) moist, moderate coarse angular blocky, non sticky and non plastic (wet), very firm (moist) and hard (dry), no root, no faunal activity, pH (H_2O) very strongly acidic (4.74).

Appendix 4: Ratings of selected soil properties

Soil Bulk Density (gcm^{-3}) Range and their interpretation

Range	General interpretation
0.9 – 1.2	Recently cultivated soils
1.1 – 1.4	Surface mineral soils, not recently cultivated, but not compacted
<1.6 – 1.8	Sand and loams
< 1.4 – 1.6	Silt
Extremely variable	Clay

Source: Landon (1991).

Soil Organic Carbon (%) Range and interpretation

Rating	Range	General interpretation
Very high	>20	Interpretation depends on soil and location
High	10 – 20	
Medium	4 – 10	
Low	2 – 4	
Very low	<2	

Source: Landon (1991).

Soil Total Nitrogen (%) Range and interpretation

Rating	Range	General interpretation
Very high	>1.0	Interpretation depends on soil and location
High	0.5 – 1.0	
Medium	0.2 – 0.5	
Low	0.1 – 0.2	
Very low	<0.1	

Source: Landon (1991).

Elemental Ratios - Ca/Mg Ratio (base on CEC)

Ratio	Range	General interpretation
Ca/Mg	>5 :1	Possible Mg and (with high pH) and P inhibition
	3 – 5 :1	Normal range
	<3 :1	Possible P inhibition and Ca deficiency

Source: Landon (1991)

Critical limits for interpreting fertility level of analytical parameters.

Soil property	Low	Medium	High
Organic Carbon (gkg $^{-1}$)	< 10	10-15	>15
Available Phosphorus (mgkg^{-1})	< 10	10-20	>20
Total Nitrogen (gkg^{-1})	< 0.2	0.2-0.5	> 0.5
Base Saturation (%)	< 50	50-80	> 80
ECEC (cmolkg^{-1})	< 6	6-12	>12

Source: Esu (1991)

Soil reaction rating (FDALR, 1985)

Rating	Range
Extremely acidic	≤ 4.5
Very strongly acidic	4.5 – 5.0
Strongly acidic	5.1 – 5.5
Moderately acidic	5.6 – 6.0
Slightly acidic	6.1- 6.5
Neutral	6.6 – 7.3
Slightly alkaline	7.4 – 7.8
Moderately alkaline	7.9 – 8.4
Strongly alkaline	8.5 – 9.0
Very strongly alkaline	>9.0

Appendix5: **Temperature and Rainfall data for Imo and Abia State**

Rainfall data for Imo State: 1980-2009 (Owerri Municipal)

D1 = 1980 – 1989				**D2 = 1990 – 1999**				**D3 = 2000 – 2009**			
Year	Total RF mm	Mean RF mm	% Rainfall	Year	Total RF mm	Mean RF mm	% Rainfall	Year	Total RF mm	Mean RF mm	% Rainfall
1980	2398.2	199.9	10.41	1990	2961.3	246.8	11.78	2000	2337.2	194.78	9.15
1981	2432.7	202.7	10.55	1991	2567.4	210.6	10.21	2001	2304.3	192.03	9.03
1982	2404.3	200.4	10.43	1992	2424.1	202	9.64	2002	2353.7	196.14	9.22
1983	1557.9	129.8	6.76	1993	2182.8	181.9	8.68	2003	2327.8	193.98	9.12
1984	2153.2	179	9.34	1994	2626	219	10.45	2004	2762.3	203.19	9.55
1985	2396.1	199.7	10.40	1995	2622.3	219	10.43	2005	2236.6	186.38	8.76
1986	2482.9	206.9	10.77	1996	2705.5	225	10.76	2006	3209.1	267.43	12.57
1987	2075.5	173	9.01	1997	2891.4	241	11.50	2007	2961.6	246.80	11.45
1988	2563.7	213.6	11.12	1998	1640.1	136.7	6.52	2008	2470.2	205.85	9.67
1989	2581.5	215	11.20	1999	2515.4	209.6	10.01	2009	2892.8	241.07	`11.33
Total	23046	1920	100		25136.3	2091.6	100		25855.6	2127.65	100

Total rain for the three decades= 74037.9mm

Source: NIMET, 2008

Temperature data for Imo State : 1980 – 2009 (Owerri Municipal)

D1 = 1980 – 1989				D2 = 1990 – 1999				D3 = 2000 – 2009			
Year	**TotalTemp (^{0}C)**	**MeanTemp (^{0}C)**	**%Temp**	**Year**	**TotalTemp (^{0}C)**	**MeanTemp (^{0}C)**	**%Temp**	**Year**	**TotalTemp (^{0}C)**	**MeanTemp (^{0}C)**	**%Temp**
1980	**329.25**	**27.44**	**9.97**	**1990**	**333.15**	**27.76**	**10.05**	**2000**	**334.85**	**27.90**	**10.10**
1981	**328.80**	**27.40**	**9.95**	**1991**	**330.05**	**27.50**	**9.96**	**2001**	**336.90**	**27.90**	**10.10**
1982	**327.65**	**27.30**	**9.92**	**1992**	**329.90**	**27.49**	**9.96**	**2002**	**336.10**	**28.08**	**10.06**
1983	**335.60**	**27.97**	**10.16**	**1993**	**328.25**	**27.35**	**9.90**	**2003**	**338.85**	**28.01**	**10.04**
1984	**330.90**	**27.58**	**10.02**	**1994**	**324.05**	**27.00**	**9.78**	**2004**	**337.55**	**28.24**	**10.12**
1985	**327.55**	**27.29**	**9.92**	**1995**	**325.50**	**27.13**	**9.83**	**2005**	**341.60**	**28.13**	**10.08**
1986	**327.7**	**27.31**	**9.92**	**1996**	**333.05**	**27.75**	**10.05**	**2006**	**343.00**	**28.58**	**10.24**
1987	**335.55**	**27.96**	**10.16**	**1997**	**334.45**	**27.87**	**10.09**	**2007**	**323.20**	**26.93**	**9.65**
1988	**332.15**	**27.68**	**10.05**	**1998**	**340.60**	**28.38**	**10.23**	**2008**	**338.30**	**28.19**	**10.10**
1989	**328.55**	**27.38**	**9.95**	**1999**	**334.85**	**27.90**	**10.10**	**2009**	**325.10**	**27.09**	**9.71**
Total	**3303.70**	**275.31**	**100**		**3313.85**	**276.13**	**100**		**3355.45**	**279.05**	**100**

Source:NIMET,2008

Table 3. Three Decades summary on rainfall and temperature

Decades	Total Rainfall (mm)	Mean Decadal Rainfall	Total Temperature	Mean Decadal Temperature
D1(1980-1989)	**23046**	**192**	**3303.70**	**27.61**
D2(1990-1999)	**25136.3**	**209.16**	**3313.85**	**27.61**
D3(2000-2009)	**25855.6**	**212.77**	**33355.45**	**27.91**

Source:NIMET,2008

Abia State Climate Data from 2008 – 2012. (Five (5) years summary of rainfall and temperature)

	2008			**2009**			**2010**			**2011**			**2012**		
Month	**Max**	**Min**	**Rmm**	**Max**	**Min**	**Rmm**	**Max**	**Min**	**Rmm**	**Max**	**Min**	**Rmm**	**Max**	**Min**	**Rmm**
Jan	31	20	13.4	33	23	62.8	35	23	0	33	20	0	33	21	0
Feb	35	21	0.00	34	24	62.8	35	24	78.2	33	23	60	33	24	59
Mar	34	23	168.4	34	24	47.8	34	24	34.7	34	24	111.4	34	24	50
Apr	32	23	219.8	33	23	100.5	34	24	126	33	24	105.8	33	24	200
May	32	23	373.5	33	23	416.2	32	24	213.5	32	23	347.7	32	23	233.3
June	30	23	352.2	31	23	236	30	24	459	30	23	239.5	30	23	213.2
July	29	22	310.2	30	22	306.3	30	23	276.9	30	22	236.5	29	23	255.3
Aug	29	22	327.4	29	23	287.4	30	23	420.7	29	23	345.1	29	23	162.1
Sept	30	23	404	30	22	205.5	30	23	309.3	30	23	424.7	30	22	350.8
Oct	31	23	211	31	23	311.1	32	23	349.2	30	23	242.8	31	22	255.4
Nov	32	24	6.7	32	22	23.7	31	23	78.2	31	23	12	28	20	182.1
Dec	33	22	8.9	34	23	0.00	33	22	4.6	33	21	9.6	21	20	9.4
Total	**378**	**269**	**2043.3**	**384**	**275**	**2060.1**	**386**	**280**	**2350.3**	**378**	**272**	**2135.1**	**263**	**249**	**1970.6**

Source: NRCRI (National Root Crop Research Institute) Umudike Meterological unit.

Note: Max = maximum temperature, Min = minimum temperature, Rmm = Rainfall (mm).

Appendix 6. Photo plates of soil profiles

PROFILE 4 Secondary forest- Falsebedded sandstone

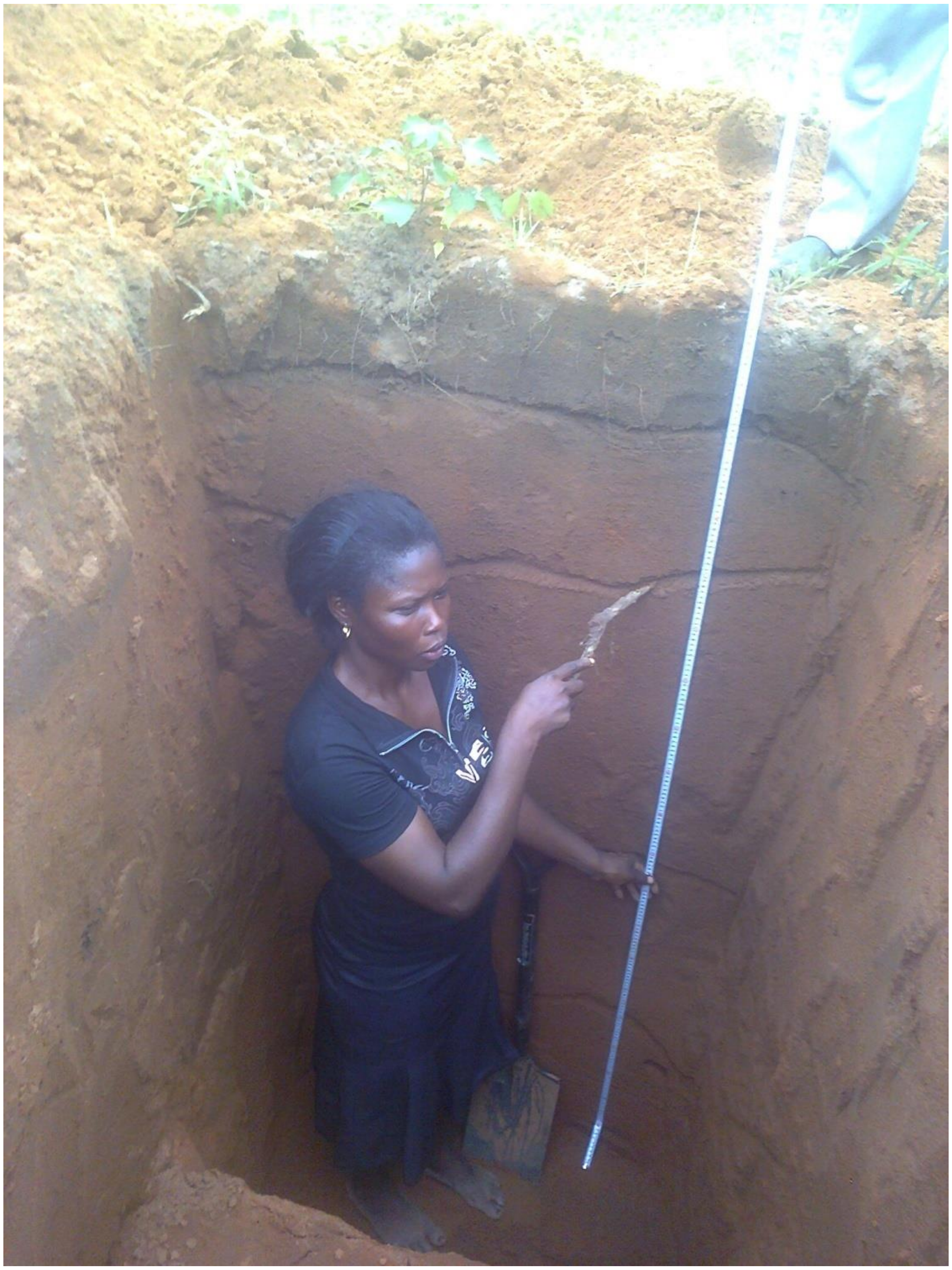
Shale fallow

Shale forest

Profile 21 sec forest Coastal plain sand.

Cultivated profile 26 Coastal plain sand.

Cultivated profile 26 Coastal plain sand.



Ahukaemere, C.M (PhD student)