EFFECT OF LAND USE AND SLOPE GRADIENTS ON SELECTED PROPERTIES AND SOIL QUALITY OF AN ALFISOL IN AFAKA FOREST, NORTHERN GUINEA SAVANNA OF NIGERIA

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JULY, 2018

DECLARATION

I hereby declare that this dissertation titled 'EFFECT OF LAND USE AND SLOPE GRADIENT ON SELECTED PROPERTIES AND SOIL QUALITY OF AN ALFISOL IN AFAKA FOREST, NORTHERN GUINEA SAVANNA OF NIGERIA' was written by me and it is a record of my own research work. It has not been presented in any previous application for a higher degree. References made to published and unpublished literature have been duly acknowledged.

HAMZA Haruna　　　　　　　　　　　　　　　　DATE

CERTIFICATION

This dissertation titled 'EFFECT OF LAND USE AND SLOPE GRADIENT ON SELECTED PROPERTIES AND SOIL QUALITY OF AN ALFISOL IN AFAKA FOREST, NORTHERN GUINEA SAVANNA OF NIGERIA' meets the regulations governing the award of Master of Science degree of Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This work is dedicated to Almighty ALLAH who inspired me to higher ideals of life.

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All praises be to Allah Almighty, the most Affectionate, the most Merciful, Who created the universe and countless salutation be upon His beloved and last Prophet Muhammad (peace be upon him), who declared that it is an obligatory duty of every Muslim to seek and acquire knowledge. I am highly indebted and express my gratitude to Allah, the most Beneficent, and the most Merciful, Who granted me the ability to undertake this research work and complete the dissertation. This gives me the privilege to acknowledge the people whose sincere help, guidance and prayers enabled me to accomplish my research work in a congenial and serene environment.

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ABSTRACT

Land use changes from forest into cultivated ecosystems result in negative impact on soil structure and quality. The purpose of this study was to determine effect of land use and slope on selected properties and quality of an Alfisol in Afaka forest, Northern Guinea savanna of Nigeria. Land use systems, including natural forest and cultivated land were identified. Eighteen (18) composite disturbed and undisturbed samples were collected from depth of 0-5 and 5-10cm for analysis of pertinent soil properties in the laboratory using rigid grid procedure. Most physical and chemical properties show relative variations in response to land use types and geomorphic positions. Mean weight diameter (MWD) indicates higher water stable aggregates of 1.26 mm in forestland and less stable aggregates in cultivated land 1.19 mm. Textural classes of soils under all the land uses on different topographic positions were sandy loam. Results indicate that the soils had high degree of weathering potentials, low to moderate bulk density at 0-5cm depth values range between 1.42 to 1.49 Mg m^{-3} in forest and cultivated land, bulk density at 5-10cm depths had values ranging between 1.34 and 1.46 1.Mg m^{-3} for forest and cultivated land respectively. Total porosity ranged from 40.77 to 46.10 % for cultivation and forest land use while slopes have 45.00, 44.48 and 44.38 % porosity for upper, middle and lower slopes respectively. The highest soil moisture contents at 0-5cm depth were 4.20, 2.63 cm^3/cm^3 , while at 5-10cm depths values were 4.32 and 2.13 cm^3/cm^3 recorded under forest and cultivation land use. Middle slope shows higher soil moisture content of 4.35 and 4.38 cm^3/cm^3 for 0-5 cm and 5-10 cm respectively. The pH (H_2O) ranged from 6.9 to 7.16 in the land uses. The electrical conductivity in the land uses was 0.13 dS/m and 0.12 dS/m was obtained for forest and cultivation land respectively, with highest EC at upper slope 0.16 dS/m. The organic carbon concentration of 10.2 g kg^{-1} and 8.2 g kg^{-1} was obtained in forest and cultivated land and highest carbon stock of 1522.1 C kg ha^{-1} was recorded at forestland with 1124.3 C kg ha^{-1} at cultivation land. The CEC of 8.60 cmol kg^{-1} and 8.54 cmol kg^{-1} was recorded on forest and cultivated land uses, whereas highest CEC value of 9.28 cmol kg^{-1} was recorded at middle slope. The exchangeable bases (Na, K, Mg and Ca) were medium rating in all land use and slope positions. The total nitrogen content of 1.21 g kg^{-1} and 1.11 g kg^{-1} for forest and cultivation land uses was recorded. The highest available phosphorus of 8.78 mg kg^{-1} and 5.47 mg kg^{-1} was recorded under cultivated and forest land use while lowest value 4.12 mg kg^{-1} of available phosphorus was recorded at middle slope. The highest carbon: nitrogen ratio 8.6:1 was obtained under forestland and 7.5:1 was obtained at cultivated land. Highest aluminum concentration of 0.14 and 0.26 cmol kg^{-1} was obtained at forest and cultivated land use. Alfisols at the upper forest land had better soil quality than those at other slope positions. Results indicate that soil fertility parameters were moderate to low in soils of cultivated land and all slope positions, suggesting that soil fertility management is required in order to make agriculture sustainable on Afaka area.

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INTRODUCTION

1.1 Background of study

Nigerian Sudan savanna zone is situate between latitude 9°3' and 12°31' N and longitude 4° and 14°3' E which covers about 22.8 million hectares representing about one quarter of Nigeria’s geographical area (Odunze, 2006). The region is characterized by high annual average temperature (28-32°C), short wet season and long dry season (6-9 months), abundant short grasses (<2 m) and a few scattered trees (Lal, 1997). Large expanse of arable land exists in the Sudan Savanna Zone of Nigeria with potential for the production of largely grain crops like maize, sorghum, millet, rice and wheat (FFD 2012). Most Nigerian Savanna soils are highly weathered and fragile with low activity clays, thus making their fertility decline under continuous arable cropping (Odunze 2006; FFD, 2012). Generally, soil productivity declines rapidly when vegetation cover is lost and inappropriate management practices are adopted (Lal 1997), thereby resulting in soil organic matter depletion and reduced agricultural productivity and food security.

Population increase and the need to achieve food security; especially in Nigeria, has given rise to clearing of forests for agricultural land use (Osakwe, 2014). Tropical soils are inherently fragile and therefore, sensitive to land use and management since removal of soil cover and subsequent tillage are activities that are likely to affect soil physical and chemical properties and micro aggregate stability (Osakwe, 2014).

Important soil property to consider for assessing soil quality under forest or cultivated land use is aggregate stability of soil. Soil aggregate is considered as soil quality indicator that provides information on soil’s ability to function as a basic component of the ecosystem (Martinez *et al*., 2012). Micro aggregate stability may be a good indicator of erodibility of Tropical soils (Igwe and Obalum, 2013). Oguike and Mbagwu (2009) demonstrated that micro aggregate stability measured by aggregated silt plus clay (ASC), Water dispersible clay (WDC), Clay dispersion index (CDI) and Clay flocculation index (CFI) were affected by land use. Soils that have high water dispersible clay are vulnerable to surface sealing, crusting and limits infiltration, thereby increase runoff (Chang *et al*., 1994). Obi (1982), in an assessment of micro aggregate stability under different land use types in a tropical Nigerian soil, revealed a strong dependence of soil aggregation on land use (Igwe and Obalum, 2013). Gochin and Asgan (2008) investigated effects of land use (forest, pasture and cultivation) on soil quality, and reported 41-89 % less dispersible clay in the forest than in their cultivated counter parts. These studies noted that frequent cultivation caused deterioration of soil quality and enhanced erosion through decreased mechanically dispersed clay. Curtin *et al*. (1994) demonstrated that higher clay plus silt in water stable aggregates of forest than in cultivated soils' mineralogy and soil organic carbon appear to influence micro aggregate stability in Tropical soil but the major micro aggregating agent in tropical soil is iron (Fe) and aluminum (Al) oxides. However, the micro aggregating effect of iron sometime could be masked in soils with relatively high soil organic carbon content (1.6 - 6.9 %) as reported by (Opara, 2009); adding that soil organic carbon can also act as a micro aggregating agent or as a facilitator to micro aggregating effect of iron and Aluminum oxide (Igwe and Obalum, 2013). Soil organic carbon is an important soil property because of its hydrophobic characteristics that has the ability to reduce slaking which precedes dispersion. Mbagwu and Bazzoffi (1998) demonstrated that 70% of variations in water dispersible particles were accounted for by organic matter. Brubaker *et al*. (1992) indicated that clay dispersion in water had been found to significantly correlate with total content of clay. Savanna Alfisols are low in inherent fertility, organic matter, cation exchange capacity, and dominated by low activity clays (Odunze, 2003). Savanna Alfisols also support production of crops such as maize, sorghum, millet, cowpea, groundnut, soya beans and cotton, and are cultivated continuously and intensively. This continuous and intense cultivation of soils in the zone has resultant effect of accelerated soil erosion, soil nutrient depletion and soil degradation (Bationo *et al*., 2003).

Another important physical and chemical soil property controlling solubility of many soil nutrients and influence soil fertility is pH of the soil. For example, Monges *et al*. (2013) did not find any significant variation in soil pH across land use types while Killic *et al*. (2012) showed slight change in pH with land use change. Land use affects soil fertility and productivity; this manifests as changes in soil properties such as macro nutrients (Nitrogen, Phosphorous, potassium, Calcium, Magnesium, Sulphur etc), pH, Organic matter, Cation exchange capacity, structure (Birkeland, 1984). Deforestation and cultivation of virgin tropical soils often lead to depletion of nutrients (N, P, and S) present as part of complex organic polymers (Birkeland, 1984).

Soil pH, total N, organic carbon, available P, exchangeable Ca, exchangeable Al, CEC and Al saturation significantly differed with the land use types. Lal (1996) and Shepherd *et al*. (2000) noted that variation of land use in tropical ecosystems could cause significant modifications in soil properties. In stressing the effect of this phenomenon on ecosystem, Schipper and Sparling (2000) posited that land use modifications are biologically and chemically more rapid than physical, as forest ecosystems are important ecologically and economically. Forest soils are one of the major sequesters of carbon on earth due to their high OM status (Dixon *et al*., 1994)

1.2 Statement of the problem

Continuous and intense cultivation of soils has effect on soil; resulting to soil erosion and soil nutrient depletion. This is because continuous cultivation alters soil structure and increases loss of soil organic matter which leads to soil degradation. Increasing incidence of soil degradation and the consequent impoverishment of soils have generated interest in the need for proper understanding of soil characteristics, and adoption of suitable conservation practices by farmers for sustained crop production in the study area. This changes in soil quality can be assessed by measuring appropriate indicators and comparing them with desired values (critical limits or threshold level), at different time intervals, for a specific use in a selected agro-ecosystem (Odunze *et al*., 2012). Slopes have been shown to affect temperature of the soil, vegetation establishment and moisture levels. These factors in turn can affect the distribution of soil organic matter, pH and nutrient levels (Birkeland, 1984).Soil reaction (pH) trends and nutrient levels are usually associated with vegetation and can also be affected by slope aspect (Birkeland, 1984).

1.3 Justification

As population growth in Northern Nigeria increases, it may require additional farmlands for food production, leading to cutting and converting forest land to cropland. Clearing of forests for agricultural production and grazing is widespread, particularly in savannas of Nigeria. The prevailing semi-arid climate in Afaka area renders the ecosystems more vulnerable and less resilient to changes in land use. The destruction of natural forest and pasture ecosystems and conversion to cropland can reduce soil productivity because of increased erosion, nutrient mining and decline in fertility, changes in aeration and moisture content, salinization or change in soil flora or fauna (Bossuyt *et al*., 1999). Effects on vegetation and species distribution have been documented in different ecosystems following anthropogenic activities (Peterken, 1974; Six *et al*., 2000; Bruun *et al*., 2001; Foster *et al*., 2003). Land use-induced changes in nutrient availability may influence secondary succession and biomass production (Foster *et al*., 2003) and reduce soil organic carbon (SOC); which plays a crucial role in sustaining soil quality, crop production and environmental quality (Doran and Parkin, 1994). Such changes directly affect soil physical, chemical and biological properties; such as soil water retention and availability, nutrient cycling, gas flux, plant root growth and soil conservation (Gregorich *et al*., 1994). Maintenance of SOC is especially important due to its effect on soil nutrient status and structural stability. Afaka study area is facing the problem of deforestation, over grazing, poor soil management and severe erosion. Combating and minimizing on-going soil degradation and enhance land productivity through sustainable use of soil resources requires understanding the soil physico-chemical characteristics under different land use systems. However, very little information is available about the study area. Therefore the present study was undertaken to evaluate effect of different land use systems and slopes on selected physical and chemical properties of different land use system in Alfisols of Afaka area.

1.4 Hypothesis

I: Conversion of forest land to cultivation causes change in soil properties

II: Subjecting of forest land to cultivation reduces soil carbon stock

The major objective of this work is to evaluate the effect of land use and slope on selected properties of an Alfisols in Afaka Forest Northern Guinea Savanna

1.5 Aim and objectives of the study

The general objective of this study is to evaluate the effect of land use and slope gradient on selected soil properties and quality of a Paleustalfs in Northern Guinea savanna of Nigeria. The specific objectives are:

1. To determine the effect of land use and slope gradient on selected properties and soil quality of an Alfisol in Afaka forest Area, Northern Guinea Savanna
2. To determine soil selected physical and chemical quality changes that occurred with slope position in the soil when forest land was converted to cultivated land use.
3. To assess the effect of forest and cultivation on soil organic carbon stock (SOC)

CHAPTER TWO

LITERATURE REVIEW

2.1The Savanna of Nigeria

Nigeria is located in the tropical zone (between, latitude 9°3' and 12°31' N and longitude 4° and 14°3' E) with a vast area having savanna vegetation (Jagtap, 1995). This is a region that is diverse; necessitating classification into derived savanna, southern Guinea savanna and northern Guinea savanna ecologies. These classifications reflect environmental characteristics; such as length of growing period; which for instance is 151-180 days for the northern Guinea savanna, 181-210 days for the southern Guinea savanna and 211-270 days for the derived savanna/coastal savanna (Jagtap, 1995). Major soils found in the various agro-ecological zones have coarse-textured surface, are low in organic matter and chemical fertility. Although yields can be improved by addition of inorganic and organic fertilizer, this can only be sustained and assured with good soil physical qualities. Soil physical qualities can be sustained at a high level with conservation tillage measures. The Nigerian Savanna region is currently witnessing increase in intensity of agricultural land use, to meet the demand of an ever increasing population (Wani *et al.*, 1995).

2.2 Land use

This involves management and modification of natural environment into built up environment; such as settlements and semi-natural habitats; such as arable fields, pastures and managed woods (Keshava and Raghu, 2015). Land use refers to man’s activities and the varied uses which are carried on over land (Keshava and Raghu, 2015). Land use management practices have major impact on natural resources; including water, soil, nutrients, plants and animals. Land use information can be used to develop solutions for natural resource management issues; such as salinity and water quality. For instance, water bodies in a deforested region or eroded areas will have different water quality from areas that are forested. Forest gardening; a plant-based food production system is believed to be the oldest form of land use in the world. Depending on land use, climate and vegetation, soil characteristics; such as soil organic matter (SOM), aggregation and aggregate stability (Shukla *et al*., 2007), bulk density, water retention (Lal, 2004), pH and nutrient status and soil biota (Islam and Weil, 2000) tend to change. Land use change is one of the main drivers of environmental change; being a major issue of global environmental change and an important component in understanding sequence of change in the characteristics and interactions of human activities with the environment. This change influences basic reserves of land and a variety of natural processes; including soils; which are not static, hence more susceptible to change in their nutrient and moisture content. The dynamics of soil nature describes conditions of a specific soil due to land use and management practices (Karlen *et al.*, 2003). Land use influences soil aggregation, aggregate stability and overall soil health (Herrick *et al.*, 2002). Land use changes have great influence on many soil physical and chemical properties; mostly soil organic matter, affecting its quality attributes and fertility. Land use practices affect the distribution and supply of soil nutrients by directly altering soil properties and influencing biological transformations on the rooting zone (Odunze *et al.*, 2002).

2.3 Land use, land-use change and forestry

Land use changes; especially cultivation of erstwhile forested land may rapidly diminish soil quality, as ecologically sensitive components of Tropical forest ecosystems are not able to buffer effects of intensive agricultural practices. As a result, severe deterioration in soil quality may lead to a permanent degradation of land productivity (Kang and Juo, 1986; Nardi *et al*., 1996; Islam *et al*., 1999). Land use, land-use change and forestry (LULUCF) is defined by the United Nations Climate Change Secretariat as "A greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities. Land use, land-use change and forestry have impacts on global carbon cycle and as such, these activities can add or remove carbon dioxide (or, more generally, carbon) from the atmosphere, influencing climate change and global warming (Odunze, *et al*., 2017).

2.4 Concepts of soil quality, degradation and sustainability

Soil quality is defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Brady and Weil, 1999). Thus, soil quality assessment reflects biological, chemical and physical properties, processes and their interactions within each resource unit (Karlen *et al*., 2001). Over the last decade, soil quality has been one of the topics of great interest in Soil Science, so much so that a database such as the Soil Science CAB Database (CAB International Publishing) supplies more than 1500 publications that use the term ‘soil quality’ as a key word. Interests have been focused on defining the concept of soil quality and searching for reliable ways for assessing the quality of soils. In recent years, defining soil quality has put into consideration the key involvement of the soil in crop production, water and atmospheric purification and thus emphasis is laid on the role of the soil both for production and for environmental quality improvement. This has led to a profusion of definitions of soil quality, but that of Karlen *et al*. (1997) which states that "soil quality is the capacity of a specific kind of soil to function, within forest or cultivated land that sustain plant and animal productivity, maintaining water and air quality, support human health and habitation", is widely accepted. Some important soil functions include; water flow and retention, solute transport and retention, physical stability and support, retention and cycling of nutrients, buffering and filtering of potentially toxic materials and maintenance of biodiversity and habitat (Andrews *et al*., 2004).

Similarly, attempts have been made to separate the concept of soil quality from that of soil health. The limits of the two concepts are not particularly clear, but it is currently accepted that the term quality refers to the aptitude of the soil for carrying out a specific function, while health refers to its overall condition (Doran and Safely, 1997; Doran, 2002). In spite of the large number of scientific papers that choose soil quality as a keyword, less than 20% deal with the estimation and quantification of the level of soil quality. This lack of proper evaluation of soil quality may well be a reflection of its difficulty; Nortcliff (2002) stated that the search for quantitative index for soil quality is difficult. This is especially so when one considers that many changes take place over the long term, and thus a change in soil quality can only be perceived when all the effects are combined over a long period of time. Authors often concentrate on finding out which soil properties best reflect the change in soil quality. Though soil quality is affected by a large number of properties, majority choose a small group of edaphic properties (basically biological and biochemical properties) to assess soil quality.

In order that the quality of soils are adequately protected, basic assessment of soil health and quality is necessary to assess degradation status and changing trends following different land use and agricultural management practices (Larson and Pierce, 1994, Lal and Stewart, 1995). This is intended to provide baseline for monitoring and evaluating soil status over time, mitigate degradation trends and ensure environmental and crop production sustainability (Doran and safely 1997; Doran and Zeiss, 2000, Hedlund *et al.* 2003). In Asia, adverse effects on soil health and quality arise from nutrient imbalance in soil, excessive fertilization, soil pollution and soil loss processes (Zhang *et al*., 1996; Odunze *et al*., 2012). The continued absence of easily applicable checklist and threshold limits for monitoring soil quality place limitations on scientists' efforts at ensuring sustainable crop production and environmental quality maintenance (Odunze *et al*. 2012). Changes in soil quality can be assessed by measuring appropriate indicators and comparing them with desired values (critical limits or threshold level), at different time intervals, for a specific use in a selected agro-ecosystem (Odunze *et al*., 2012., 2013., 2017).Such a monitoring system will provide information on the effectiveness of selected farming systems, land use practices, technologies and policies (Arshad and Martin, 2002; Odunze *et al*., 2015). Also, Gomez *et al.* (1996) proposed a framework for evaluating sustainability at farm level in the Philippines based on field indicators that take into account both farmer's satisfaction and resource conservation. They observed that high yield, low labour requirement, low input cost, high profit, and stability are some features that are likely to enhance farmer satisfaction. Natural resource conservation is usually associated with soil-depth, water holding capacity, nutrient balance, organic matter content, ground cover, and biological diversity (Reginald *et al*. 2007; Odunze *et al*. 2012; Odunze *et al*., 2015). According to these researchers, an indicator is said to be at a sustainable level if it exceeds a designated trigger or threshold level and thresholds are tentatively set, based on the average local conditions (Gomez *et al*. 1996).

When a soil is degraded, its capacity to produce biomass is reduced. Recovery of the soil through efforts to rehabilitate it depends on inherent capacity of the soil and the level of degradation reached before rehabilitation efforts; i.e., soil resilience (Brady and Weil, 1999).

Soils of savanna region are physically fragile because the topsoil contains a large proportion of sand, causing weak aggregation, because of the low level of organic matter in this layer. The physical constraints are further compounded in gravelly soils or soils with shallow depth overlying plinthic or hardpan layers (Adeoye and Mohammed-Saleem, 1990; Salako *et al.,* 2002).

2.5 Soil quality Indicators

The quality of soil is rather dynamic and can affect the sustainability and productivity of land use. It is the end product of soil degradative or conserving process and is controlled by chemical, physical, and biological components of a soil and their interactions (Parr *et al*, 1992). Indicators, however, will vary according to the location and the level of sophistication at which measurements are likely to be made (Riley, 2001). Therefore, it is not possible to develop a single short list, which is suitable for all purposes. Riley (2001) also emphasized the range of likely indicators rather than the use of single indicator.

Identification of biological indicators of soil quality is reported as critically important by several authors (Doran and Parkin, 1994; Abawi and Widmer, 2000) because soil quality is strongly influenced by microbiological mediated processes with particular importance to identify those components that rapidly respond to changes in soil quality (Roaming *et al*., 1995). Biological indicators of soil quality that are commonly measured include soil organic matter, respiration, microbial biomass and mineralizable nitrogen. Soil organic matter plays a key role in soil function, determining soil quality, water holding capacity and susceptibility of soil to degradation (Giller and Cadisch, 1997; Feller *et al*., 2001). In addition, soil organic matter may serve as a source or sink to atmospheric Carbon dioxide (Lal, 1997a) and an increase in the soil Carbon content is indicated by a higher microbial biomass elevated respiration (Sparling *et al.,* 2003).

In order to achieve high crop yields smallholder farmers have to provide soil nutrients in large quantities (Sanchez and Swaminathan, 2005). Therefore it is possible to alter the pool of available nutrients by adding inorganic fertilizers, incorporating cover crops, and using other organic materials in form of manures and composts (Stocking, 2003). Results of chemical test are soil quality indicators which provide information on the capacity of soil to supply mineral nutrients, which is dependent on soil pH. Soil pH is an estimate of the activity of hydrogen ions in soil solution. It is also an indicator of plant available nutrients. High activity is not desirable and the soil may require liming with the base cations Ca or Mg in order to bring the solution back to neutral.

Soil physical properties are estimated from the soil's texture, bulk density (a measure of compaction), porosity, water-holding capacity (Amezketa *et al.,* 1999). The presence or absence of hard pans usually presents barriers to rooting depth. These properties are all improved through additions of organic matter to soils. Therefore, suitability of soil for sustaining plant growth and biological activity is a function of its physical properties (porosity, water holding capacity, structure, and tilt) Larson and Pierce, (1994).

There are several criteria to consider when selecting soil quality indicators. In general,

I. Easy to assess.
II. Able to measure changes in soil function both at plot and landscape scales.
III. Assessed in time to make management decisions.
IV. Accessible to many farmers.
V. Sensitive to variations in agro-ecological zone.
VI. Representative of physical, biological or chemical properties of soil.
VII. Assessed by both qualitative and/or quantitative approaches. Larson and Pierce, (1994).

2.6 Minimum data set for soil quality indicator

A general outline is necessary to evaluate soil quality. That outline can be used to check changes in the environment associated with agricultural management. A minimum data set (MDS) of soil factors has been proposed by Larson and Pierce (1994) and it is generally accepted that such factors should be easy to calculate and present differences in management. Minimum data set (MDS) was proposed to measure soil quality and its changes due to management practices through selection of key indicators such as organic matter, pH, nutrient status, bulk density and rooting depth (Larson and Pierce, 1994). Collecting an MDS helps to identify relevant soil indicators and correlate them with significant soil and plant properties. It is a minimum set of indicators required to obtain a complete understanding of the soil indicators examined. Moreover, they provide a useful tool for evaluating the status, health and quality of soil (Doran *et al*., 1996; Larson and Pierce, 1994; Doran and Parkin, 1994). Sufficiently detailed experiments need to be conducted to develop meaningful assessments of soil status, often expressed as an index of soil quality (Kang *et al*., 2005, Odunze *et al*., 2012). When measurements are taken, values are subjected to the standardization procedure called scoring function, which, according to Anikwe (2006) involves the conversion of measured value to unit-less values usually between 0 and 1. There are four general types of scoring functions used in soil quality assessment;

1. More is better (higher measurement means higher soil quality e.g soil organic matter),
2. Less is better (lower measurement means higher soil quality e.g bulk density),
3. Optimum range (moderate range of values is desirable, e.g pH),
4. Undesirable range (a specific range of value is undesirable).

The basic soil quality indicators selected for a minimum data set in this study include: data on bulk density, organic carbon, total nitrogen, available phosphorus cation exchange capacity (CEC), soil pH (H_2O(1:2.5), pH ($CaCl_{2)}$ (0.01M) and mean weight diameter (dry and wet)

2.7 Soil quality indices

Various soil quality indexing methods (Granatstein and Bezdicek, 1992; Andrews and Carroll, 2001) have been applied to develop a range of critical test values. The soil quality assessments can be defined within these values. A soil quality index is developed to standardize measured soil quality parameters and produce a numeric value which can be used to assess changes in soil over a period of time and to compare soils (Wienhold *et al*., 2009). Various soil assessment methods have been proposed to examine effects of management practices on overall soil quality (Wienhold *et al*., 2009). These include

MDS, Soil conditioning index (SCI), Soil Management Assessment Framework (SMAF) and Agro-ecosystem Performance Assessment Tool (AEPAT). The SCI has been implemented by USDA-NRCS (Natural Resources Conservation Service) to evaluate effects of crop management on soil organic matter (USDA-NRCS, 2008). The SMAF is a comparatively recent method which relies on the consequences of management systems on changing soil properties and general soil function (Andrews *et al*., 2004; Karlen *et al*., 2011). The AEPAT is a research oriented index methodology that quantifies performance of management practices for selected functions (Liebig *et al*., 2001). Hence, assessment of soil quality should be achieved most efficiently using a modeling framework based on collecting and synthesizing an array of soil quality indicators (Karlen *et al*., 1997).

The SMAF consist of three steps: indicator selection, indicator interpretation, and integration into a soil quality index (Andrews *et al*., 2004). The indicator selection step uses an expert system of decision tools to recommend indicators for inclusion in the assessment based on the user's stated management goals, location and current practice. For instance, if the user is adding manure, soil test P is suggested as one indicator to include in the assessment. In the indicator interpretation step, observed indicator data is transformed into a unitless score based on clearly defined, site-specific relationships to soil function. The soil functions of interest include crop productivity, nutrient cycling, physical stability, water and solute flow, contaminant filtering and buffering, and biodiversity. The indicator interpretation step uses various factors (i.e organic matter, texture, climate, slope, region, mineralogy, weathering class, crop, sampling time, and analytical method) to adjust threshold values in the scoring curves that are then used to assign a relative value of 0 to 1 for each type of data being collected. The integration steps allows for the individual indicator scores to be combined into a single index value. This can be done with equal or differential weighting for the various indicators depending upon the relative importance of the soil functions for which they are being measured (Diak and Stott, 2001). Soil Management Assessment Framework (SMAF) was adopted in this study to assess changing soil properties and general soil function.

2.8 Soil Physical Properties

2.8.1 Soil moisture and aggregation

Aggregate stability of soil often exhibit large inter-annual seasonal variability. Such variability occurs; regardless of residue treatment, due to direct influence of climate on soil moisture (Perfect *et al.,* 1993; Angers *et al.,* 1999). Further, though aggregate stability is measured on air dried sample, the antecedent water content has been shown to affect aggregate stability (Caron *et al.,* 1992). The effects of moisture on aggregate characteristics have no consistent consequences on soil aggregate size and stability (Yang and Wander, 1998). Effects of soil moisture on soil structure are still unclear, since both increase and decrease in water stable aggregate have been observed following wetting and drying (Denef *et al.,* 2001). The contradictory result found in literature can be explained by differential initial moisture condition of aggregates, organic matter content, intensities and duration of drying and wetting phases and aggregate stability methods. As suggested by Denef *et al.,* (2001), inter annual and seasonal variability in aggregate stability results from seasonal wetting and drying interacting with accumulation of plant and microbial debris associated with the growing plant.

2.8.2 Water content and retention capacity

Soil water content is the basic parameter required to answer wetness, quantity of water held in soil, amount of water absorbed before surface runoff started, and amount of water a particular soil supplies to maintain optimum growth (Kamara *et al*., 1992). Availability of soil moisture to plants is a function of water input, moisture retention and rooting depth of a given soil, which is governed by inherent soil properties and management practices. In general, roots are able to readily absorb soil moisture at field capacity, depending on mineralogy and soil structure, and become less able to do so with decreasing water content to reach permanent wilting point (Rowell, 1994). Soil stratification or layering can markedly influence available water and its movement in the soil. Impervious soil layers drastically slow down rate of water movement and restricts penetration of plant roots, thereby reducing the soil depth from which moisture is drawn by plant roots (Kamara *et al*., 1992).

Soil water contents at field capacity (FC), permanent wilting point (PWP) and available water holding capacity (AWHC) increased with depth for soils under different management practices (Wakene, 2001; Ahmed, 2002). The increases of these three components of soil moisture holding capacity with depth were positively and significantly correlated with increase of clay fractions of soil with profile depth. Variation in topography, land use and soil attributes all affect distribution of soil moisture (Ahmed, 2002).

2.8.3 Cultivation, soil physical properties and crop production

Cultivation involves physical manipulation of the soil to prepare seedbed for crop production (Lal, 1997a). Thus, the most profound effect of cultivation is in relation to soil physical properties. For socio-economic and cultural reasons, manual tillage is still widely practiced in Africa, as farming is largely at subsistence level. However, there are now a number of commercial farms; especially for cash crop production, in many parts of Africa. Many of these are located in areas hitherto reserved as forest and need for sustainable production is pertinent to maintain ecological balance (Lal, 1997b).

Soil physical properties which are altered by tillage are bulk density, water content, penetration resistance, soil temperature and aggregate stability. Tilled plots are more susceptible to soil erosion; as soil aggregates will be loosened, which leads to alteration of soil texture (Lal, 1997b). Available water content and water infiltration were highest under no- tillage and both were particularly low for ridge-tilled plots (Lal, 1997a). Less erosion of particles enhanced water retention in no- till while high infiltration rates were due to high macroporosity (Lal, 1997a).

Mound tillage was also found to improve soil bulk density significantly, compared to flat tillage in compacted soils ameliorated with planted fallows in southwestern Nigeria (Lal, 1997a). Such improvements in bulk density encourage root growth either for cereals, tuber crops or root crops in ridge tillage, mound tillage and deep tillage in different agro-ecological zones (Adeoye and Mohamed-Saleem, 1990; Salako *et al*., 2001). Rapid drying and increase in soil temperature on ridges and mounds occur if they are not mulched. Lal (1997b) advocated management of gravelly Alfsols in southwestern Nigeria with no tillage on short slopes (less than 100 m length) as the rate of increase in bulk density was higher for conventionally tilled plots compared with no tillage. An interesting observation by Kirchhof and Salako (2000) was that after fallowing a degraded Alfisol; caused by tillage and soil erosion in southwestern Nigeria for 6 years, the previously tilled plots under bare fallow (tilled up and down slope without crop cover) and conventional tillage still recorded more soil losses (1.78-2.83 t/ha) than the previous no tillage plots (1.34 t/ha). These results indicate that soil degradation caused by tillage cannot be easily obliterated. A land user should carefully weigh the options for tillage and no tillage before embarking on tillage. Conventional tillage should be avoided while conservation tillage should be practiced when tillage is adopted.

2.8.4 Physical Properties of Forest Soils

Physical properties of forest soils develop under natural conditions by the influence of permanent vegetation over a long period of time (Osman, 2013). Physical properties of forest soils may be almost permanent properties unless modified by harvesting operations, shifting cultivation and/or forest fires. Important physical properties of forest soils include texture, structure, porosity, density, aeration, temperature, water retention and movement. The physical properties of forest soils affect every aspect of soil fertility and productivity (Osman, 2013). Soil physical properties determine the ease of root penetration, availability of water and ease of water absorption by plants, amount of oxygen and other gases in the soil, and the degree to which water moves both laterally and vertically through soil. Soil physical properties also influence natural distribution of forest tree species, growth and forest biomass production. However, soil physical properties are largely controlled by size, distribution, and arrangement of soil particles (Fuhrer, 2000).

2.8.5 Soil Texture

Soil texture refers to the degree of fineness or coarseness created by close packing of variously sized particles in a soil. It is determined by the relative proportion of sand, silt and clay in a soil. Soil texture is not usually changed by management practices (Osman, 2013). Soil texture is inherited from the parent materials and it originates through weathering and pedogenic processes; including re-crystallization, eluviation and illuviation. It may however be altered by erosion, deposition, truncation, landfill, etc (Osman, 2013). Soil texture is determined in the laboratory by a technique based on the velocity of fall of a particle in a liquid medium, which is proportional to the square of radius of the particle and inversely to the viscosity (a fluid's internal resistance to flow) of the liquid (Stokes' Law, Hillel, 1982). Percentages of sand, silt, and clay are determined by either "pipette method" or "hydrometer method" (Hillel *et al.*, 1982). Soil textural class names can be obtained from "USDA textural triangle (Fig 1), if the percentages of any two size fractions are known. For example, lines for 40% sand and 20% clay intercept to be named sandy clay loam Brady and Weil, (2002)

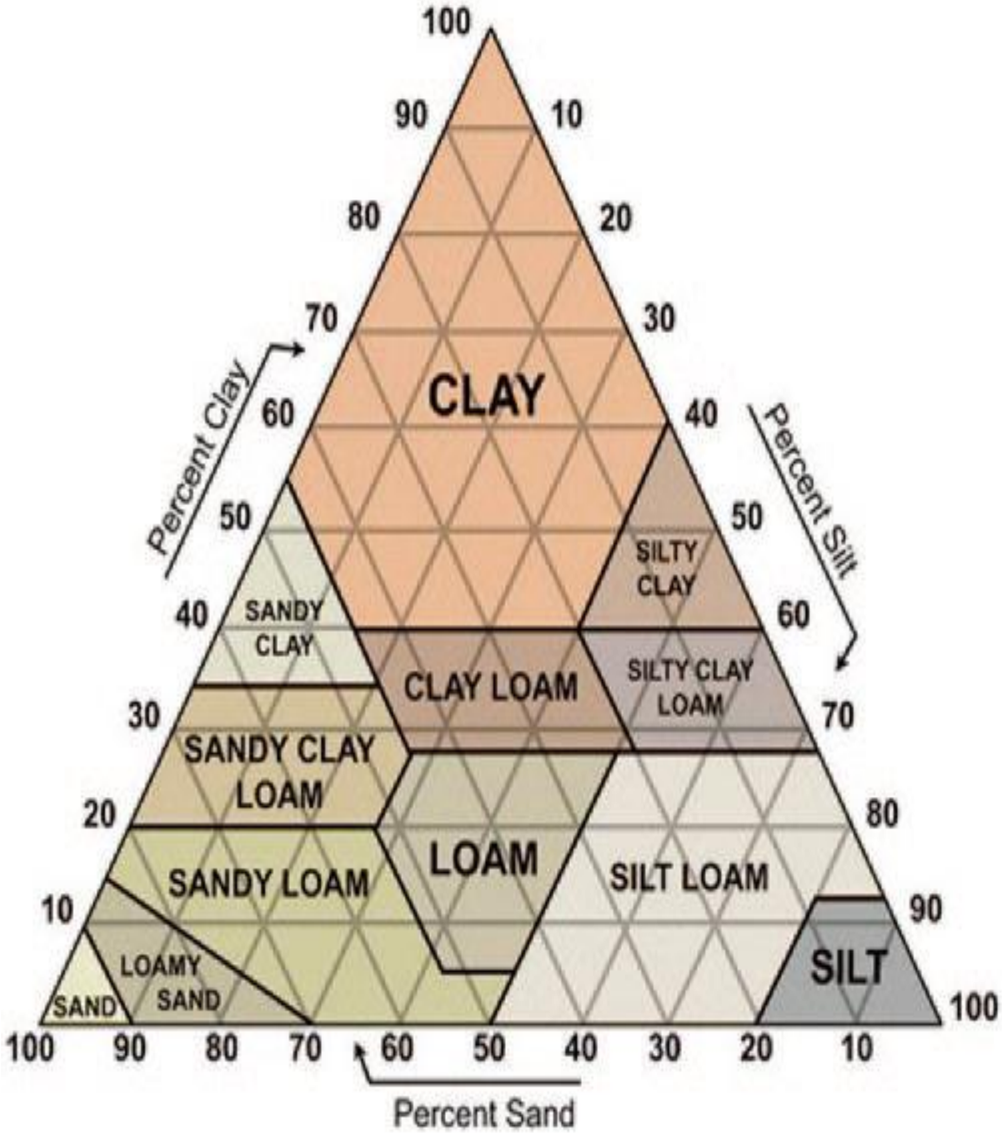

Fig 1 Soil Textural Triangle (Brady and Weil, 2002)

2.8.6 Soil texture and species distribution

According to Jha and Singh (1990), soil texture governs most properties of the soil, its permeability, capacity to retain water, degree of aeration, ability to make nutrients stored in clay–humus complex available to plants, ability to withstand mechanical working of top soil and its ability to support a permanent plant cover. Jha and Singh (1990) suggested that soil texture is an important factor in the constitution and distribution of dry tropical forest communities. Soil texture was said to be largely responsible for the distribution of hardwood species within an old growth forest. The higher clay content (and presumably higher moisture and fertility) of upland soils have allowed for development of a forest type that closely resembles forests (Osman *et al.,* 2013). Salako *et al*. (2003) found obvious relationship between soil particle-size distribution and tree species composition in a forest stand of Finland.

2.8.7 Soil structure

Soil structure is the arrangement of soil particles into units of different sizes and shapes. These units are called peds or aggregates and the processes of formation of peds are collectively called aggregation. According to Lal (1997a), soil structure refers to the size, shape and arrangement of solids and voids, continuity of pores and voids, their capacity to retain and transmit fluids and organic and inorganic substances, ability to support vigorous root growth and development. Peds differ from “clods” and “concretions”; clods or chunks are artificially formed (such as by plowing) hard soil mass. Concretions are hard lumps produced by precipitation of dissolved substances (usually iron and manganese oxides). In some soils and sediments, the particles are not aggregated but remain separated; such soils are called single grained, such as some sandy soils. Most soils are structured. In some soils; such as heavy clays, all the particles adhere together. Structure of these soils is called massive. Soil structure determines pore-size distribution, which affects water flow and erosion potential (White, 1985), microbial and faunal behavior (Edwards and Bremner, 1967; Elliot *et al*., 1980; Van veen *et al.,* 1984) and organic matter dynamics (Campbell and Souster, 1982; Tisdall and Oades, 1982; Schimel, 1986). Aggregation may affect nutrient turnover by controlling microbial predation (Van Veen *et al*., 1984) and by protecting organic matter from microbial degradation (Young and Spycher, 1979). Soil compaction is the physical consolidation of soil by an applied force that destroys soil structure, compresses soil volume, increases bulk density, reduces porosity and limits water and air movement (Osman, 2013).

Stunted growth of trees, badly formed tree roots, standing water, and physically dense soil are some signs of forest soil compaction. Texture, structure, organic matter and water are important soil factors that determine susceptibility of a soil to compaction. Soils made up of particles of about the same size compact less than soil with a variety of particle sizes (Osman, 2013). Hard, dense, low-organic matter soils suffer more from compaction than loose, friable, high-organic matter soils. A dry soil is not easily compacted; soil compaction increases with increase in soil water content until a moist condition is reached. Wet soils are also less susceptible to compaction. When soil is compact, soil strength is increased and total porosity is reduced at the expense of large pores. Thus, volumetric water content and field capacity are increased, while air content, water infiltration rate, and saturated hydraulic conductivity are decreased, if a soil is compacted (Osman, 2013). Compacted soils offer physical impedance to root extension, which affects water and nutrient absorption. Soil compaction caused by harvesting operations can affect future regeneration and growth of trees (Salako *et al*., 2001). Available soil water content is reduced when a soil is compacted (Osman *et al.*, 2013). When this occurs, nutrients and water may become limited because plant's demands exceed ability of the root system to access these resources (Unger *et al*., 1994). Nutrients have limited mobility in compacted soil (Unger *et al.*, 1994); so nutrient deficiencies may seriously limit tree growth there. Forest soils may be compacted by grazing animals and by expanding roots of the trees themselves, but more noticeably by vehicles used for a range of mechanized forest operations.

Harvesting machinery may be very heavy, combined with pushing, pulling and lifting of logs,that may exert large pressures on the soil. Some harvesting operations may greatly disturb the soil (Greenland *et al*. 1981). Compaction of forest soils may be caused by:

1. Trafficking by heavy equipment during felling, forwarding, skidding and site preparation operations;
2. Dragging action of logs as they are moved from stump to the landing; and
3. Slash disposal and creation of planting or seeding sites during site preparation.

The main forces causing compaction of forest soils are mostly heavy machinery used during timber harvesting and mechanical site preparation (Greenland *et al*. 1981)

2.8.8 Soil structure formation and tree growth

Aggregation results from complex interactions of many factors; including the environment, soil management, plant influences and soil properties; such as mineral composition, texture, soil organic matter, pedogenic processes, microbial activities, exchangeable ions, nutrient reserves and moisture availability (Tisdall and Oades, 1982). There are several mechanisms of aggregation. Aggregates are formed in stages, with different bonding mechanisms dominating at each stage (Tisdall and Oades, 1982). According to Dudal *et al*., (1993), aggregation results from the rearrangement of particles, flocculation and cementation. Clay particles are electrically charged particles, they carry both negative and positive charges, but there are generally higher numbers of negative charges on their surfaces. They attract cations. When clay particles adsorb and get satisfied largely with monovalent cations like Na^+ and K^+, they remain dispersed in a liquid medium. Clay particles may come closer in a suspension only when they are flocculated (Dudal, and Decaers, 1993).

Soil structure; which modifies soil texture, exerts important influence on edaphic conditions and the environment (Bronick and Lal, 2005). Soil structure regulates pore size, number of pores, and distribution of pores and total porosity of the soil. Thus, retention and movement of soil water including infiltration, permeability, percolation, drainage, leaching, etc. all depend on soil structure. Soil structure affects tree growth by influencing root distribution and the ability to take up water and nutrients (Bronick and Lal, 2005). Soil structure facilitates oxygen and water infiltration and can improve water storage (Franzluebbers, 2002). Microbial processes; like organic matter decomposition, mineralization, stabilization, nitrification, and nitrogen fixation are influenced by soil structural conditions. Bronick and Lal, (2005) reviewed literature on the relationship of soil structure and plant growth and suggested that root–soil contact; which influences water and nutrient uptake, depends on soil structure. Aggregation may affect nutrient turnover by controlling microbial predation (Van Veen *et al*., 1984) and by protecting organic matter from microbial degradation (Van Veen *et al*., 1984).

2.8.9 Bulk density

Bulk density is the weight per unit volume of oven dried soil, which is commonly expressed as Mg m^{-3}. Bulk density is a measure of pore space in soils and is required for the determination of compactness; as a measure of soil structure, for calculating soil pore space, as an indicator of aeration status and water content and also provides information on the environment available to soil microorganisms (Barauah and Barthakulh, 1997). Bulk densities normally decrease as mineral soils become finer in texture. Bulk densities vary within soil texture (Landon, 1991). For example, bulk density of cultivated clay, clay loam and silt loam topsoil may range between 1.0 and 1.6 Mg/m^3 (Landon, 1991), whilst that of sand and sandy loams usually show variation between about 1.2 and 1.8 Mg m^{-3} (Landon, 1991). Very compacted soils may have bulk densities exceeding 2 mg cm^{-3} use uniform units (Landon, 1991). Bulk densities of soils are inversely related to amount of pore space and soil organic matter, which is influenced by land use and management, practices (Landon, 1991). Any factor that influences soil pore space will affect bulk density. Intensive cultivation also increases bulk density and it ranges between 1.02 and 1.89 mg/cm^3 (Landon, 1991). Meek *et al*. (1992) indicated that tillage operation with heavy machinery increased bulk density from 1.70 to 1.89 mg/cm^3 and decreased infiltration rate by four times. Moreover, intensive grazing was found to increase soil bulk density in soil, especially at the surface (Bell *et al*., 1997).

2.8.10 Total porosity

The total porosity of soils usually lies between 30% and 70% (Foth, 1990). In soils with the same particle density, the lower the bulk density, the higher is the percent total porosity. As soil particles vary in size and shape, pore spaces also vary in size, shape and direction (Foth, 1990). Coarse textured soils tend to be less porous than fine texture soils, although mean size of individual pores is larger in the former than in the latter. There is close relationship between relative compaction and larger (macrospores) of soils (Ike and Aremu, 1992). Also, tillage reduces macro pore spaces and produces a discontinuity in pore space between cultivated surface and the subsurface soils (Ike and Aremu, 1992). Generally, intensive cultivation causes soil compaction and degradation of soil properties including porosity. Thus, although a sandy soil has relatively low total porosity, movement of air and water through such soil is rapid because of dominance of macro pores. Fertile soils with ideal conditions for most agricultural crops have sufficient pore space, more or less equally divided between large (macro) and small (micro) pores. Decreasing organic matter and increasing clay that occur with depth in many soil profiles are associated with a shift from macro-pores to micro-pores (Brady and Weil, 2002).

2.9 Aggregation and aggregate stability in soils

2.9.1 Processes and important of aggregation in Soils

Soil aggregation is the process whereby primary particles (sand, silt, and clay) are bound into secondary units, usually by natural forces and substances derived from root exudates and microbial activity (Lal 2004). This dynamic process is complex because of interaction of many abiotic factors and processes involved (Topp *et al.*, 1992; Bronick and Lal, 2005). Several theories and conceptual models have been proposed to figure out the soil aggregation process (Amezketa, 1999). Most of these models claim that soils consist of ever changing aggregates of different sizes bound by organic and inorganic compound (Tisdall and Oades, 1982). Lal (2004) reported a different model underlying soil aggregation, including both directions from microaggregate to macroaggregate or the opposite. Among these models, Tisdall and Oades (1982) model described aggregate hierarchy in which soil organic matter (SOM) is considered the principal binding agent of aggregate formation and starts with microaggregate before macroaggregates. This model was revised by Oades (1984) who indicated that roots and hyphae holding macroaggregate (>250 µm) together form the nucleus of microaggregate (20 to 250 µm) formation in the centre of macroaggregates. Six *et al.* (1999) identified four dynamic stages of macroaggregate turnover, microaggregate formation, soil organic carbon stabilization in microaggregate. Their model indicated that macroaggregates are stabilized by fresh plant debris, root and fine inter-aggregate particulate organic matter. The fine organic particle is sequestered in microaggregates formed inside the macroaggregate. Stable micro aggregates are released and then built into new macroaggregates. Generally, aggregates produced from these processes occur in a variety of sizes; often grouped into macro aggregate (>250 µm) and microaggregate (<250 µm) (Tisdall and Oades, 1982). Aggregate size orders are varied in their response to these environmental stresses with macroaggregates being more susceptible to disruptive forces than microaggregates. Horn and Smucker (2005) reported that aggregate formation and aggregate strength depend on swelling- shrinking processes and biological activities. Aggregate stability is often used as a measure of soil structure. Soil aggregate distribution and stability measurement have been proposed as soil quality indicators (Six *et al.,* 2000). Soil structure is an important soil property to be evaluated because it mediates many biological and physical processes in soil (Six *et al.,* 2000; 2002). For example, soil structure determines porosity and infiltration, hence water availability to plant and soil erosion susceptibility (Six *et al.,* 2000). Well aggregated soils provide stable contraction for farm implements, adequate soils' physical condition for penetration, growth and anchorage of plant roots and free drainage with moderate retention of rain water. Further, well aggregated soil are more resistant to erosion than primary particle of sand, silt, clay and organic matter. Johnson (1992); Ellert and Gregorich (1995) suggested that it is very important to maintain soils' structure to improve land management practices and reduce environmental impact of agricultural practice. Stability of soil aggregates is related to such complex factors as organic matter content and composition, microbial action, inorganic binding agent, clay mineral and clay content, physical properties (surface area, soil moisture content etc.) and management practices (Oades, 1986; Goldberg *et al.*, 1988); as a result, mechanism for stabilization of soil aggregates vary with soil types

2.9.2 Methods of measuring soil aggregation and aggregate stability

Methods of evaluating aggregate stability of soil were proposed (Yoder, 1936) and arose due to diverse factors and mechanisms of disaggregation which act on different organizational structures of soil reflected by compression of entrapped air, differential swelling of clays; which provoke micro fissuration of aggregates, impact of rain drops and physiochemical dispersion. Soil aggregate stability depends on their mineral and organic constituents, exchangeable sodium percentage, oxide and hydroxide of iron and aluminum (Saikh, *et al*., 1998b) and soil organic matter (Haynes and Swift, 1990).

Several pre-treatments have been proposed and used by numerous authors to accommodate the different mechanisms of soil disaggregation. A pre-treatment described by Yoder (1936) with modification by Mikha and Rice (2004) stated that 50 g of dried soil sample be placed on top of a sieve and slaked by rapidly adding one liter of water until the soil is covered by water. The submerged soil is left in water for ten minute before wet sieving. Different aggregate size classes can be obtained, dried, subsampled and used to determine sand content of each fraction. Subsample of intact aggregate (2-5 g) with a five-fold volume (10-25 ml) of 5 g sodium hexametaphosphate was left over and shaken for four hours. The dispersed organic matter and soil collected on 53 mm mesh sieve is washed with deionized water and dried at 105 ^{0}C for 24 hrs to estimate sand aggregates. This method is more recent then other methods.

Elliott *et al* (1980) adopted a wet sieving method in aggregate size separation. In his work, soil samples obtained at field capacity were passed through a set of three sieves at room temperature (21^{0}C) to obtain four aggregate size classes namely >2000 µm (large macro-aggregate); 250-2000 µm (small macro-aggregate); 53-250 µm (micro-aggregate) and <53 µm (silt and clay fraction). Prior to wet sieving, moist soil sample is passed through 8 mm sieve and air dried. The sample is then submerged on top of a 2 mm sieve for about 5 mins before sieving. The sieving is an automated process moving the sieve up and down at a height of about 3 cm for about 50 consecutive times within an interval of 2 mins. After the removal of organic material that floats on top of the water, the sample will be poured to the next sieve size and the same sieving procedure repeated. The aggregate fractions that were retained in each sieve are then oven dried at 50^{0}C for 24 hrs, weighed and stored. This method by Elliot (1986) was modified by Elliott and Cambardella (1991) and Cambardella and Elliott (1991), where fractionation of soil aggregates was achieved by capillary wetting of soil to field capacity to prevent slaking following immersion. Wetted soils are immersed in water on a nest of sieve (2000 µm, 250 µm and 53 µm) and shaking vertically 3 cm for 50 times in 2 mins. Soil aggregate retained on the sieve are oven dried at 50^0C for 24 hours and weighed. Materials less than 53 µm are not collected but contents are determined by calculating the difference between whole soil and sum of the aggregate fractions on the three nests of sieves.

Another technique of estimating aggregate stability was described by Kemper and Rosenau (1986). Soil sample placed on nest of sieves of diameter 2 mm, 1 mm, 0.5 mm and 0.25 mm are pre-soaked in distilled water for 10 mins before oscillating vertically in water along amplitude. The resistant aggregates are oven dried at 105^0C for 24 hrs, weighed and corrected for sand fraction to obtain the proportion of true aggregate, the method is simple.

The pre-treatment described by Kemper and Rosenau (1986) involves wetting of soils under constant head (3.0 cm of water) and separated into five aggregate size classes (2000 µm, 250 µm, 106 µm, 53 µm <53 µm by wet sieving using a 2 cm stroke for 300 secs at 0.52 cycle s^{-1}. Aggregates are then dried on the sieves in a dehumidifying chamber (10^0C, 24 hrs), transferred to beakers, and dried at 35^0C (48 hrs.) before recording the final dry masses. Subsamples of each fraction 0.25-2.0 g) are dried at 105^0C to allow correction to a final dry weight, this method cumbersome.

The dry aggregate size distribution is performed by mechanically or manually shaking nest of sieves to obtain different size fractions. Van Bavel (1950) method was modified by Kemper and Rosenau (1986) and is used to estimate mean weight diameter (MWD) for both wet and dry stable soil aggregates. The MWD is calculated as sum of mass fractions remaining on each sieve after sieving, multiplied by mean aperture of the adjacent sieve. Thus,

a) $MWD = \sum_{i=1}^{n} x_i \omega_i$

Where x_i = mean diameter of any particular size range of aggregates separated by sieve

ωi = weight of aggregates in the size range as fraction of the total dry weight of sample

ń =addition, there are often complications when different site and /or management practice are compared for soil structural differences by means of the MWD.

2.10 Inorganic binding agents

Polyvalent cations (aluminum and iron) improve soil aggregation through bridge formation between inorganic minerals or clay and soil organic carbon (SOC) (Anikwe *et al.,* 2010). Aggregates containing clays, aluminum and iron oxides or hydroxides promote soil organic carbon incorporation; conferring aggregate stability (Bone *et al.,* 2008: Matus *et al.,* 2006) to demonstrate that soil organic matter accumulation in Chilean volcanic soils is produced by Al stabilization rather than climatic condition and clay content of the soil. Some scientist reported positive effect of Fe on aggregation (Colombo and Terrent, 1991; Igwe *et al.,* 1995), whereas others observed no effect (Greenland *et al.,* 1981). The reason for this variable effect of Fe on aggregation may not be unconnected with difference between Fe not determined in their studies or other soil characteristics that influence aggregating capacity of Fe.

Bivalent cations; such as calcium (Ca) and magnesium (Mg), also improve aggregation. However in some soils, Mg may have deleterious effect on aggregation due to higher swollen effect on clays present in such soil (Zhang *et al*., 1996). Calcium is a critical element for stabilization of soil organic matter and soil aggregates through its role in the formation of clay-polyvalent cation-organic matter complex Odunze, 2003). Organic matter stabilization effect is mostly observed at micro-aggregation level (Grant *et al.,* 1992; Odunze *et al.,* 2013) because Ca exacts its effect at the organo-minerals complexion scale. It can also indirectly increase macro-aggregation by stimulating microbial activity in acid soil (Chang and Heenan, 1999).

2.11 Management practices

The negative effect of unsustainable land use and management practices on soil physical properties and resulting soil degradation have been widely recognized. Management practices influence soil aggregation by affecting dynamics of carbon (quantity and quality of soil organic matter) and the function of microbial population to varying degree depending on soil type and climate (Lawal *et al.,* 2009). In this regard, management practices including tillage methods, residue management, amendment application, organic matter management and crop rotation among others can have enormous influence on soil aggregation and its stability (Bone *et al.,* 2008). Tillage is a major factor dictating loss of soil organic matter (SOM), hence aggregate disruption in addition to crop residue removal by grazing or harvesting (Lawal *et al*., 2009). Repeated inverting and pulverizing soil exposes soil organic matter to mineralization, compact the sub soil and disturb plant and animal communities (Bone *et al.,* 2008). The process leads to decrease in organic matter (SOM), CEC and reduction in potential biological and biochemical activities (Doran. and Safely, 1997; Riffaldi *et al.,* 2002). Further, root and fungal network are disrupted, decreasing the stability of soil aggregates and favouring leaching, losses of nutrient and erosion (Odunze, 2006). Aggregate dynamics vary among different crops, crop rotations and cover crop (Bronick and Lal, 2005). The influence of different crops is dependent on their chemical composition and roots, tending to be short lived under tillage (Chan and Heenan, 1996). Cover crops increase carbon input, CEC and soil aggregate stability and may enhance microbial biomass. The influence of crop and crop rotation is important on soil aggregation due to plant root and their rhizosphere effect. Root enmeshes, realigns soil particle and release exudates, which result in physical, chemical and biological alteration that influence soil aggregation (Bronick and Lal, 2005). Aggregation tends to increase with increasing root length, density, microbial association and glomalin, among others (Rillig *et al.*, 2002). Aggregate stability is greater in rhizosphere soil than non rhizosphere soil (Caravac *et al.*, 2002) due to increased rhizo-deposition, root density, root turnover, hyphal growth and microbial biomass; all of which directly or indirectly are influential in maintaining particle together.

2.12 Chemical properties

Soil chemical properties are important among factors that determine nutrients' supplying power of soil to plants and microbes. The chemical properties of soil affect mineral solubility and nutrient availability to crop plants, give soils their ability to hold nutrients, create a desirable chemical environment for plant growth and sustainability of ecosystem health (Sumner, 2000). Soils have characteristic chemical properties that are the results of weathering of plants and animals (Kimmins, 1997). The chemical reactions that occur in soil affect processes leading to soil development and soil fertility build up. Minerals inherited from soil parent materials overtime release chemical elements that undergo various changes and transformations within the soil (Kimmins, 1997).

2.12.1 Soil reaction (pH)

Soil reaction (usually expressed as pH value) is the degree of soil acidity or alkalinity. This is caused by particular chemical, mineralogical and/or biological environment. It is generally viewed as a “master variable” because it regulates almost all biological and chemical reactions in soil (Brady and Weil, 1999). Continuous cultivation practices, excessive precipitation, steepness of topography and application of inorganic fertilizer could be attributed as some of the factors responsible for reduction of pH in soil profiles (Mokwunye, 1978; Ahmed, 2002). Distribution of soil pH may provide a useful index of weathering status, potential nutrient holding capacity and fertility of soil types. Soil pH is mostly related to nature of parent material, climate, organic matter and topographic situation (Tamirat, 1992). The soil in high altitude and those higher slopes had low pH values, probably suggesting the washing out of solutes from these parts (Belay, 1996; Abayneh, 2001; Mohammed *et al*., 2005). Soil reaction (pH) affects nutrient availability and toxicity, microbial activity and root growth. Thus, it is one of the most important chemical characteristics of soil solution because both higher plants and microorganisms respond so markedly to their chemical environment. Descriptive terms commonly associated with certain ranges in pH are extremely acidic (pH < 4.5), very strongly acidic (pH 4.5-5.0), strongly acidic (pH 4.5-5.2), moderately acidic (pH 5.3-5.9), slightly acid (pH 6.0-6.6), neutral (pH 6.7-7.3), moderately alkaline (pH 7.4-8.0), strongly alkaline (pH > 8.0), and very strongly alkaline (PH > 9.1) (Tekalign, 1991). The degree and nature of soil reaction are influenced by different anthropogenic and natural activities including leaching of exchangeable bases, acid rains, decomposition of organic materials, application of commercial fertilizers and other farming practices (Rowell, 1994; Miller and Donahue, 1995; Tisdale *et al.*, 1995; Brady and Weil, 2002).

2.12.2 Cation exchange capacity (CEC)

Cation Exchange Capacity is defined as the capacity of soils to adsorb and exchange cations (Brady and Weil, 2002). It is the ability of soil solid phase to attract or store and exchange cation nutrients within soil solution and render them available to plants through exchange reaction (Odunze, 2002). Cation exchange capacity is an important parameter of soil because it gives indication of type of clay minerals present in the soil, its capacity to retain nutrients against leaching and assessing their fertility and environmental condition. Generally, chemical activity of the soil depends on its CEC. The CEC of a soil is strongly affected by amount and type of clay and amount of OM present in the soil (Curtis and Courson, 1981). Both clay and colloidal OM are negatively charged and therefore can act as anions (Kimmins, 1997)**.** As a result, these two materials, either individually or combined as a clay-humus complex, have the ability to adsorb and hold positively charged ions (cations). Soils with large amounts of clay and OM have higher CEC than sandy soils. In surface horizons of mineral soils, higher OM and clay contents significantly contribute to CEC, while in the subsoil particularly; where Bt horizon exist, more CEC is contributed by clay fractions than by OM due to the decline of OM with profile depth (Foth, 1990; Brady and Weil, 2002). A soil with high CEC and most exchange site occupied by H or Al ion is not fertile soil. For a soil to be able to make plants grow well, both CEC and percent base saturation (PBS) should be high (Brady and Weil, 2002). A soil with PBS less than 20 % is considered to be low, 20-60 % medium and greater than 60 % high fertility (Landon, 1991). According to Gao and Change

(1996), CEC is highly correlated with OC content of soil, which in turn is affected by soil management practice; such as intensive cultivation, fertilization and variation in land use type. They may be dissolved in soil solution, from where they can be utilized directly.

An exchangeable cation capacity is one that is held on a negatively charged surface and displaced by another cation. The exchangeable cation is a desirable form of a nutrient being quickly brought into solution and made accessible to roots by exchange with proton. Although cation nutrients held on exchange sites form a readily available pool, they do not represent the cation supplying ability of the soil (Binkley and Sollins, 1990; Binkley *et al*., 1992). Cations removed from exchange sites often are replenished rapidly from other sources; such as organic matter (OM) decomposition, mineral weathering, or release of ions fixed within layers of clay minerals.

Generally, processes that affect texture (such as clay) and organic matter (OM) due to land use variation also affect CEC of soils. Woldeamlak and Stroosnijder (2003) reported that CEC value was highest in soils under forest and lowest under cultivated land.

2.12.3 Exchangeable bases (K, Na, Ca and Mg)

Exchangeable Mg commonly saturates only 5 to 20 % of effective CEC, as compared to 60 to 90 % typical for Ca in neutral to somewhat acid soils (Mesfin, 1998). Research works conducted on Ethiopian soils indicated that exchangeable Ca and Mg cations dominate exchange sites of most soils and contributed higher to total percent base saturation, particularly in Vertisols (Mesfin, 1998; Eylachew, 2001). Different crops have different optimum ranges of nutrient requirements. The response to calcium fertilizer is expected from most crops when exchangeable Ca is less than 0.2 cmol (+)/kg of soils, while 0.5 cmol (+)/kg soil is reported to be the deficiency threshold level for Mg in the tropics (Landon, 1991). Soils in areas of moisture scarcity (such as in arid and semi- arid regions) have less potential to be affected by leaching of cations than do soils of humid and sub-humid regions (Jordan, 1993). Soils under continuous cultivation, application of acid forming inorganic fertilizers, high exchangeable and extractable Al and low pH are characterized by low contents of Ca and Mg mineral nutrients resulting in Ca and Mg deficiency due to excessive leaching (Dudal and Decaers, 1993).

Soil parent materials contain potassium (K) mainly in feldspars and micas. As these minerals weather, the K ions released become either exchangeable, exist as adsorbed or as soluble in the solution. Potassium is the third most important essential element next to N and P that limit plant productivity (Brady and Weil, 2002). Its behavior in the soil is influenced primarily by soil cation exchange properties and mineral weathering rather than by microbiological processes (Brady and Weil, 2002). Unlike N and P, K causes no off-site environmental problems when it leaves the soil system (Brady and Weil, 2002). It is not toxic and does not cause eutrophication in aquatic systems (Brady and Weil, 2002). Wakene (2001) reported that variation in distribution of K depends on the mineral present, particles size distribution, degree of weathering, soil management practices, climatic conditions, degree of soil development, intensity of cultivation and parent material from which the soil is formed. The greater the proportion of clay mineral high in K, the greater will be the potential K availability in soils. Soil K is mostly in mineral form and the daily K needs of plants are little affected by organic associated K; except for exchangeable K adsorbed on organic matter (OM) Wakene (2001). Mesfin (1998) noted low presence of exchangeable K under acidic soils while Alemayehu (1990) observed low K under intensive cultivation. Normally, losses of K by leaching appear to be more serious on soils with low activity clays than soils with high- activity clays and K from fertilizer application move deeply (Alemayehu 1990).

Exchangeable sodium (Na) alters soil physical and chemical properties mainly by inducing swelling and dispersion of clay and organic particles, resulting in restricted water permeability and air movement, crust formation and nutritional disorders (decreased solubility and availability of calcium (Ca) and magnesium (Mg) ions (Szabolcs, 1969; Sposito, 1989). Moreover, it also adversely affects the population, composition and activity of beneficial soil microorganisms directly through its toxicity effects and indirectly by adversely affecting soil physical as well as chemical properties (Sposito, 1989). In general, high exchangeable Na in soils causes soil sodicity which affects soil fertility and productivity.

2.12.4. Organic matter (OM)

Soil OM is defined as any living or dead plant and animal materials in the soil and it comprises a wide range of organic species such as humic substances, carbohydrates, proteins and plant residues (Dudal and Decaers, 1993 Foth and Ellis, 1997;). Soil organic matter arises from the debris of green plants, animal residues and excreta that are deposited on soil surface and mixed to a variable extent with mineral component (White, 1997). Removal or burning of residues exposes soil to negative climatic impacts and deprives soil organisms of their primary energy source (White, 1997). Organic matters existing on soil surface as raw plant residues help protect the soil from effect of rainfall, wind and sun. Humus is the substance left after soil organisms have modified original organic materials to a rather stable group of decayed products as is the colloidal remains of OM (Sopher and Baird, 1982). Foth (1990) indicated that distribution of organic matter; expressed as organic carbon, is 38 % in trees and ground cover, 9 % in forest floor and 53 % is in soil, including roots plus organic matter (OM) associated with soil particles. In most tropical environments, conversion of forest vegetation to agricultural land results in a decline of soil organic matter (OM) content to a newer, lower equilibrium (Woldeamlak and Stroosnijder, 2003). Most cultivated soils of Ethiopia are poor in OM contents due to low amount of organic materials applied to the soil and complete removal of biomass from field (Yihenew, 2002), and due to severe deforestation, steep relief condition, intensive cultivation and excessive erosion hazards (Eylachew, 1999). Biological degradation is frequently equated with depletion of vegetation cover and OM in the soil, but also denotes reduction of beneficial soil organisms that are important indicator of soil fertility (Oldman, 1993). The cultivated soil on upper slope positions exhibit high OM and total N when compared to the less eroded cultivated soils on foot slope and toe slope positions (Belay, 1996). The relatively high OM and total nitrogen (N) content of soils probably resulted from frequent fallowing and addition of organic manure (Belay, 1996)

2.12.5. Total Nitrogen (TN)

Nitrogen is one of the most essential elements that are taken up by plants in greatest quantity after carbon, oxygen and hydrogen, but is the most frequent deficient nutrient in crop production (Havlin *et al*., 1999). The total N content of a soil is directly associated with its organic carbon (OC) content and its amount on cultivated soils is between 0.03 % and 0.04 % by weight (Mengel and Kirkby, 1987). The N content is lower in continuously and intensively cultivated and highly weathered soils of humid and sub humid tropics due to leaching and in highly saline and sodic soils of semi-arid and arid regions due to low OM content (Tisdale *et al*., 1995). Wakene (2001) reported that there was a 30 % and 76 % depletion of total N from agricultural fields cultivated for 40 years and abandoned land respectively, compared to virgin land in Bako area, Ethiopia. It ranges from less than 0.02 % in subsoil to greater than 2.5 % peat soils, attributed to the general low biomass production and fast oxidation of organic matter in such climate zone (Havlin *et al*., 1997). There is a strong positive relationship between soil nitrogen and soil organic matter content. Low total nitrogen content and therefore N deficiency is visible in highly weathered and sodic soils of arid and semi- arid regions due to low organic matter content which is attributed to the general low biomass production and fast oxidation of organic matter in such climatic zones (Havlin *et al*., 1997)

2.12.6 Available phosphorus

Phosphorus (P) is an essential element classified as a macronutrient because of the relatively large amounts of P required by plants. Following N, P has more wide spread influence on both natural and agricultural ecosystems than any other essential element. In most natural ecosystems, such as forests and grasslands, P uptake by plants is constrained by low total quantity of the element in soil and by very low solubility of the scarce quantity that is present (Brady and Weil, 2002). The main sources of plant available P are weathering of soil minerals, decomposition and mineralization of soil OM and commercial fertilizers.

One of the main roles of P in living organisms is in the transfer of energy. Adequate P availability for plants stimulates early plant growth and hastens maturity. Although P is essential for plant growth, mismanagement of soil P can pose a threat to water quality. Variability of the level of available P is related to land use, altitude, slope position and other characteristics, such as clay and calcium carbonate content (Mohammed *et al*., 2005).

2.12.7 Electrical conductivity

Electrical conductivity (EC) is a measure of salinity. In addition to overcoming some of the ambiguities of total dissolved salt measurement, electrical conductivity (EC) measurement is quicker and sufficiently accurate for most purposes (Bohn *et al.,* 2001). Excessive accumulation of salts is common in arid and semi-arid regions where rainfall amount (precipitation) is insufficient to leach excess soluble salts (Havlin *et al*., 1997). These salts will remain on surface soil after evaporation of limited available moisture due to high temperature. According to Landon (1991) in the soil, determination of electrical conductivity serves to give an idea of total quantity of soluble salts and the degree of salinity.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Site description

The study area is Afaka forest reserve, established in 1946, situated some 24 kilometers north –west of Kaduna and is roughly bisected by Kaduna-Tegina road (Figure 2). The area lies between Latitude $10^0 37^{'}$, N and Longitude $07^0 15^{'}$ E, near milestone 132 south of the road and currently covers an area of 129 ha (FDRF 1964).The altitude is approximately 1950 ft (585 m) above sea level. The area is virtually flat with a very gentle slope to the south. Drainage is generally imperfect due to the occurrence of compacted or indurate layers in much subsoil and not to the topography (FDRF, 1964). The mean annual rainfall is between 1011-1161 mm; which is received mainly between May to September, with peak rainfall in August (Oluwasemire and Alabi, 2004)

History of the site prior to reservation is uncertain. The area was sparsely populated, although there are traces of old village site and of ancient iron working; not far from the experimental area. Since the reserve was constituted in 1946, it has undergone several annual bush burnings. In 1955, Afaka site was selected in the north for establishment of Federal department forestry reserve (FDFR 1964)

3.2 Soils and vegetation of study area.

The soils can generally be described as varying in texture from sand in the upper horizons to sandy clay at the depth of 20-30 cm. Rounded ironstone concretions occur frequently at varying depths; sometimes associated with quartz gravels or forming indurate ironstones. This crust outcrops North West of the forest reserve area; but within the area, is not generally above 0.9144 m from the surface (FDFR, 1964).

Vegetation in the area is associated with *Isoberlinia doka* as the dominant species and *Monotesker stigii* on eroded areas bordering gully formations. *Uapacato goensis* and *Parinaricu ratellifoli*a are locally common (FDFR, 1964).

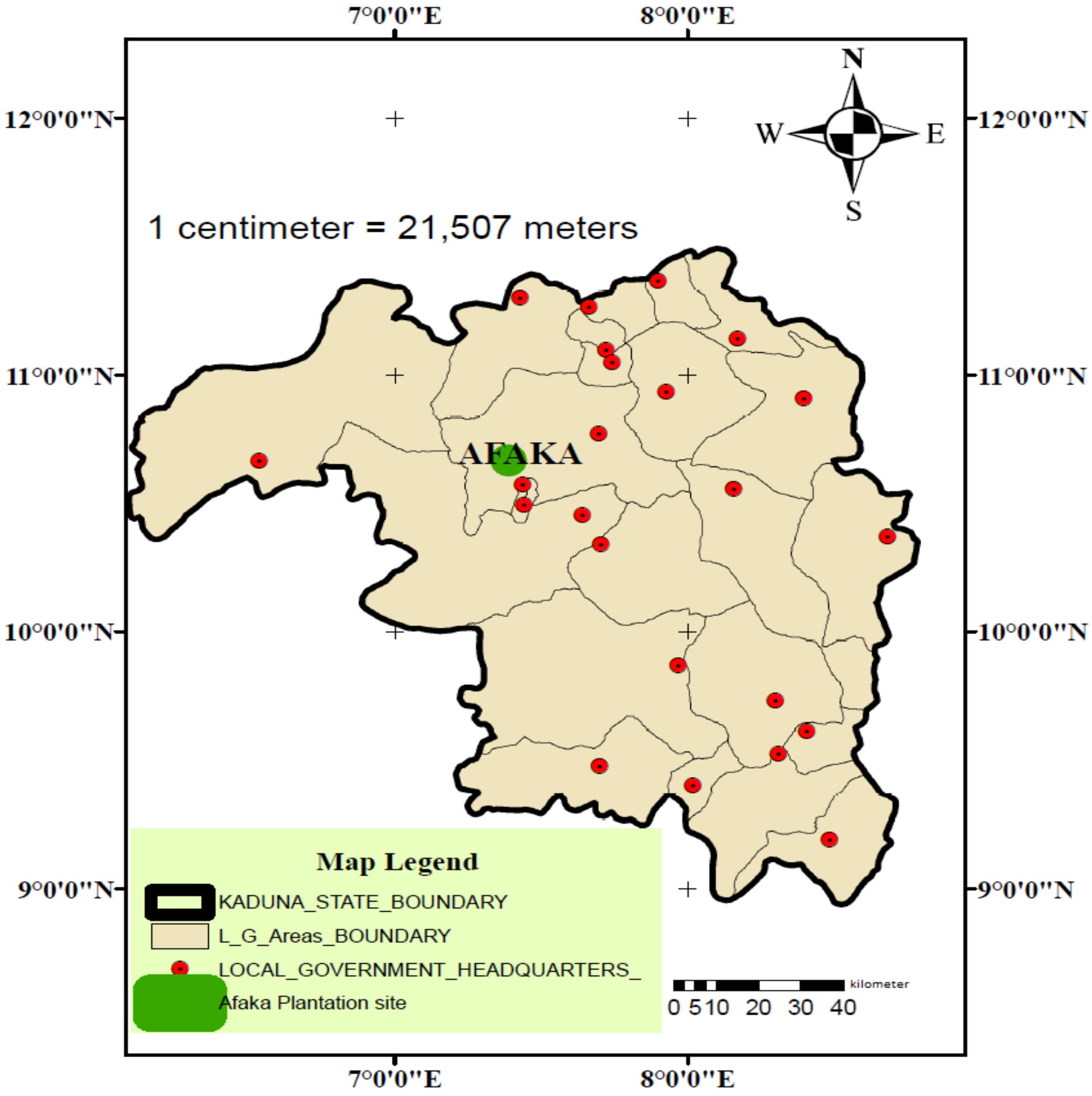

Figure 2: Map of Kaduna State showing Afaka forest reserve

Planting of Afaka Forest in all cases was 10 feet x 10 feet (3 m x 3 m) spacing for the following species. E*ucalyptus rudis,* A*lbizzia lebbek*, *Cassia siamea*, *Eucalyptus crebra*, *Khaya senegalensis,* C*assia siamea and Albizzia lebbek*, *Anogeisus leiocarpus*, *Eucalyptus camadulensis and Cassia siamea*, *Callitris robusta* (FDRF, 1964). Farming is done in the area at subsistence level with traditional hoes. Information from farmers in the location reveals that they practice continuous cultivation and some common crops grown are beans, maize and sorghum.

3.3 Geology of the study area

The study area has underlying rocks; mainly gneisses and schist of precambrian basement complex, buried under a sandy drift material (Federal Department of Forest Research, 1964).

3.4 Mapping and selection of geomorphic positions

3.4.1 Sampling plan: Soils on geomorphic positions were sampled on a rigid grid detailed survey plan.

Soil samples from depth of 0- 5 cm (top soil) and 5 -10 cm (lower layer) were collected at auger points determined along traverses from cultivated land and in adjacent forest, in each delineated geomorphic position of the study area. The sample area covered 1 km by 1 km dimension. This involved use of traverse lines perpendicular to the baseline. Natural features such as road were chosen as baseline (Figure 3). In all, ten traverse lines were proposed, such that augering was done at 100 m interval along each transverse. The different locations were selected based on identification of typical Afaka forest vegetation, identified typic-toposequence and crop cultivated sites.

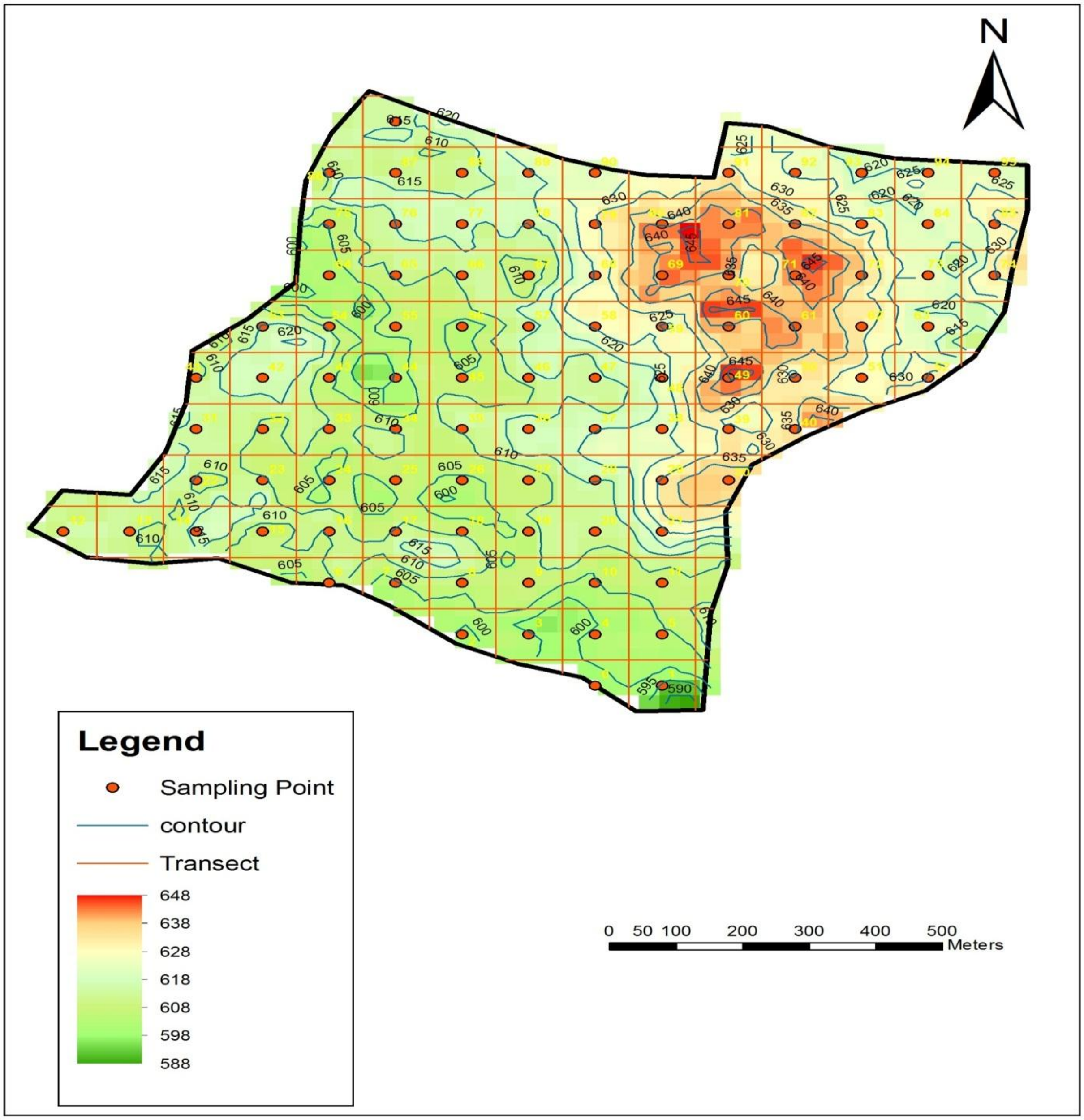

Fig 3: Map Showing Soil Geomorphic Positions and Sampling point in Afaka Forest Reserve

3.5 Determination of Soil Physical Properties

3.5.1 Aggregate separation

Aggregate size separation was determined using dry and wet-sieving methods according to Elliot (1986). Two hundred grams (200 g) of soil sieved through five mm sieve was sieved in a bucket quarter filled with water by slaking using sieve sizes of two mm (2000 µm), 0.25 mm (250 µm), 0.053 mm (53 µm) and < 0.053 mm (< 53 µm). Aggregates were physically separated into four aggregate-size fractions: (i) Large macro-aggregates (LM; > 2000 µm), (ii) Small macro-aggregates (SM; 250-2000 µm), (iii) Micro-aggregates (micro; 53 µm), and (iv) Silt and clay sized particles (SC; < 53 µm). Subsamples were slaked for 5 min by submersion in two litres of deionized water on top of a two mm sieve. During slaking, all roots and other organic debris larger than two mm floating on the surface were removed and discarded. Soils were wet-sieved under water by moving the sieve vertically 50 times in two min, carefully breaking the surface of water with each stroke. Materials passing through the sieve passed into the next smaller sieve, while materials retained on each sieve were backwash into an aluminum pan. The soil slurry passing through the 53 µm sieve was rinsed into a four litres glass dish. All size fractions were oven dried at 60 ^{o}C and stored at room temperature in glass vials.

Sand content of aggregate fractions > 53 µm were determined from sub samples of each auger point and plot. Ten grams of each aggregate fraction (if the sample weight is < 10 g then the entire fraction were used) were dispersed using 30 ml of 5 % (w/v) sodium hexametaphosphate and shaken for 18 hr on a reciprocal shaker. Silt and clay particles were washed from dispersed samples by rinsing over a 53 µm sieve to isolate sand and particulate organic matter on top of the sieve, which was backwashed into aluminum tins and dried overnight at 60 ^{o}C prior to being weighed. Organic matter content was then removed from sand by loss-on-ignition prior to determining sand weight (Cambardella *et al.,* 2001). The sand free weight of each aggregate fraction was determined by subtraction and Mean Weight Diameter (MWD) of soil sample estimated as described by Kemper and Rosenau (1986).The proportion of aggregate weight was calculated as follows:

b) $$\frac{Weight\ of\ soil\ retained\ in\ sieve\ -\%\ Sand\ contained}{Total\ weight\ of\ soil\ taken\ -\%\ Sand\ content}$$

3.5.2 Particles Size Distribution

Particle size analysis of soil samples was used to determine percentage of sand, silt and clay in the soil samples. These percentages were used to determine textural classes of soil samples. The analysis was performed using the hydrometer method (Gee and Or, 2002). Fifty grams (50 g) of a 2 mm sieve soil samples from each auger point and geomorphic position; representing the two management practices of forest and cultivated land use systems, at 0-5 and 5-10 cm depths was weighed into a 250 ml plastic container and 100 ml of sodium hexametaphosphate (Calgon) added to the soil and shaken for 10 minutes. The Calgon was prepared by adding 40 g of calgon per liters of water. The suspension was transferred into 100 ml glass cylinder and made up to mark with water. The suspension was thoroughly stirred using a plunger and a hydrometer. The readings were recorded at 40 seconds and after 2 hours.

A blank of the reagent was run and percentage of clay, silt and sand to be determined as follows:

i. $\% \, Clay = \frac{Correction \; 2 \; hours \; hydrometer \; reading \times 100}{Weight \; of \; soil \; taken}$

ii. $\% \, Silt = \frac{Corrected \; 40 \; seconds \; hydrometer \; reading \times 100}{Weight \; of \; soil \; taken}$

iii. $\% \, Sand = 100 - (\% \, Silt + \% \, Clay)$

iv. $Corrected \; reading \; C = \left(Actual \; reading - Blank \; reading\right) + 0.36T$

Where T is the room temperature minus 20^0C

3.5.3 Determination of particle density

The Stan pycnometer method using water as the displacing liquid was used to determine soil particle density for each geomorphic unit in forest and cultivation land use systems. The weight of empty pycnometer bottles was taken and 10 g of air dried soil weighed into it. 25 mls of carbon dioxide (CO_2) free distilled water was added and the content was stirred with glass rod. Air was expelled out of the content by placing the pycnometer on a hot plate until when it is about to boil. The pycnometer and its content was weighed when cold and recorded. The total mass of the bottle, water and soil was determined (Kowal and knabe, 1970).

The content was then emptied into pre-weighed 250 mls beaker which was oven dried at 105^oC to a constant weight. The beaker plus soil was weighed and weight of oven dried soil was determined by calculation:

$$\rho_p = \frac{d_w \times w_1}{w_1 - (w_2 - w_3)}$$

I. Where ρ_p is the particle density (Mgm^3),

II. w_1 is the weight of oven dried soil,

III. w_2 is the weight of pycnometer + soil + water,

IV. w_3 is the weight of pycnometer + water and

V. d_w is the density of water(Mgm^3) at room temperature.

3.5.4 Measurement of aggregates stability indices

Composite soil samples previously dried and wet-sieved through 5-mm mesh were used to calculate Macro-aggregate stability indices such as: Mean Weight Diameter (MWD), Water Stable Aggregates (WSA) and Degree of Aggregation (DOA) (Kemper and Rosenau, 1986; Zhang *et al.*, 1996).

$$MWD = \sum_{i=1}^{n} \frac{w_i}{100} d_i$$

Where

i. MWD is the Mean Weight Diameter,

ii. n is the number of sieves of aggregate fractions,

iii. d_i is the mean diameter of the ith fraction and

iv. w_i is the weight of soil in the fraction

v. i expressed as a percentage of the dry soil mass.

Water Stable Aggregates was express as WSA (% of soil > 250 µm)

$$WSA\ (\%\ of\ soil > 250\mu m) = \frac{(weight\ of\ dry\ aggregates - sand)}{(weight\ of\ dry\ soil - sand)} \times 100$$

Degree of Aggregation (DOA) was calculated using the formula:

$$DOA \quad = \quad \frac{W_a - W_b}{W_a}$$

Where W_a and W_b stand for the proportion of particles between 250 and 53 µm obtain by micro-aggregate size analysis and by particle size analysis, respectively

Micro-aggregates stability indices were calculated following the analysis of particle size distribution. This involves determination of the amount of silt and clay in calgon-dispersed as well as water dispersed samples using Bouyoucos Hydrometer method of particle size analysis as described by Gee and Or (2002).

Water dispersible clay and silt i.e., Dispersion Ratio (DR) will be calculated as follows:

$$Dispersion\ Ratio\ (DR) \quad = \quad \frac{(\%\ silt + clay\ (H_2O)}{\%silt + clay\ (calgon)} \times 100$$

$$Aggregated\ silt\ + clay\ (ASC) \quad = \quad [\ \%clay\ + silt\ (calgon)] - [\ \%clay\ + silt\ (H_2O)]$$

$$Clay\ Flocculation\ Index\ (CFI) \quad = \quad \frac{[\ \%\ clay\ (calgon)] - [\ \%\ clay\ (H_2O)]}{[\%\ clay\ (calgon)} \times 100$$

$$Clay\ Dispersion\ Index\ (CDI) \quad = \quad \frac{(\ \%\ clay\ (H_2O)}{\%\ clay\ (calgon)} \times 100$$

3.5.5 Dry sieving:

Dry aggregate size distribution was determined by dry sieving. Two hundred grams (200 g) of soil from each geomorphic unit of the land use systems was passed through a set of sieves with diameter ranging from 5 mm-0.05 mm mounted on a CSC scientific sieve shaker. The sieve was arranged in descending order of diameter from top to bottom, the <0.05 mm soil aggregates was collected in the collecting pan placed below all other sieves. The nest of sieves was shaken for 60 seconds and soil aggregates retained in each sieve was collected and weighed. The aggregate size stability characterized by mean weight diameter (MWD) is defined according to Van Bavel (1950) as

$$MWD = \sum_{i=1}^{n} x_i \omega_i$$

i. Where x_i = mean diameter of any particular size range of aggregate separated by sieve

ii. ωi = weight of aggregate in the size range as fraction of the total dry weight of sample

iii. n = number of aggregates in a size class

iv. i= individual separate which is equal to

3.5.6 Determination of bulk density

Six undisturbed soil samples from three geomorphic unit at two land use type was taking, undisturbed soil core samples of 45 mm diameter and 50 mm height from 0-5 and 5-10 cm depths were obtained for the determination of bulk density of each land use system and geomorphic location as described by Blake and Hartge (1986). The samples were oven dried at $105^{o}C$ for 24 hours after which they were weighed. The weight of empty core samplers was also taken and mass of the soil was determined. Bulk volume was obtained by measuring internal diameter and height of the cylinder, so that volume of the soil was expressed as:

$V \quad = \quad \pi r^3 h$

Where V is volume of the core (cm3), r is the radius (cm), h is the height of the core and π is 3.142

Bulk density was calculated as:

$$\rho_p \quad = \quad \frac{weight\ of\ oven\ dry\ soil}{volume\ of\ soil} \quad (\frac{g}{cm^3}) \qquad \text{Or} \qquad \text{Mgm}^{-3}$$

3.5.7 Soil moisture content

The soil moisture retention characteristics for undisturbed core samples from the study area were measured using pressure plate extractors (Klute, 1986). The moisture content of soil was evaluated at matric potential of -2, -5, -10, -33, -100, -500 and -1500 kPa. The saturated moisture content of soil was determined by equilibrating soil on the tension table without suction (i.e., at 0 kPa). The available water holding capacity was determined using water retention difference (WRD).Water retention was obtained using the mathematical expression.

$$\text{WRD (cm)} \ \frac{\{\text{FC (\%)-PWP (\%)}\}}{100} \text{ x (B/W) x D}$$

Where W = density of water =1 g/cm^3 or Mgm^{-3} B = bulk density of soil (Mgm^{-3})

D = depth of soil (m). FC = field capacity (determine at 0.3bars or -33 kPa)

PWP = permanent wilting point (determine at 15 bars or -1500 kPa) Klute (1986)

3.5.8 Measurement of saturated hydraulic conductivity

Laboratory determination of saturated hydraulic conductivity (K_S) was made with undisturbed soil cores obtained from the same depths and positions for the determination of bulk density. The constant head permeameter method as described by Reynolds and Elrick (2002) was used. This procedure allows water to move through the soil under a steady state head condition while volume of water flowing through the soil specimen is measured over a period of time. By knowing the volume V of water measured, length L of specimen, cross-sectional area A of the specimen, time t required for the volume to be discharged and head gradient (ΔH).

The hydraulic conductivity was calculated using Darcy's laws as follows:

$$K_s = \frac{VL}{A\Delta Ht}$$

Where:

K = saturated hydraulic conductivity; cm/min

V = Volume of soil; cm

t = time; minutes

A = Area; cm

L = Length of soil core; cm

ΔH = change in hydraulic head; cm.

3.5.9 Porosity

Total Porosity was obtained from the particle and bulk density determined for each geomorphic position and land use system. It was calculated as:

$$Porosity\ (\%) = \frac{particle\ density - Bulk\ density}{particle\ density} \times 100$$

3.6 **Determinations of chemical parameters**

3.6.1 Determination of soil pH

Soil pH of each soil sample obtained from auger points was determined both in water and 0.01M$CaCl_2$ solution, using a soil to solution ration of 1:2.5 (Rhoades, 1982)

3.6.2 Organic carbon

Soil organic carbon was determined by the Walkley-Black wet oxidation method by (Nelson and Sommers, 1982). One gram of 2 mm sieved soil samples was weighed into a 250 ml conical flask and 5 ml of 1N potassium dichromate ($K_2Cr_2O_7$) solution was added and the flask gently swirled. Also, 10 ml of concentrated sulphuric acid (H_2SO_4) was added into the flask and allowed to stand for 30 minutes. Then 100 ml of distilled water was added and allowed again to cool for 30 minutes. The organic carbon (OC) was determined by titrating this digest with 0.5 N ferrous ammonium sulphate $[NH_4)_2SO_4.FeSO_4.6H_2O]$ to a red (maroon) end point. The organic carbon content was calculated using the following formulae:

$$\text{OC \%} = \frac{(\text{Blank titre} - \text{Actual titre}) \times 0.3 \times m \times f}{\text{Weight of air dried soil taken}}$$

Where f =correction factor =1.33,

$$m = \text{concentration of } FeSO_4 = \frac{\text{Concentration of } K_2Cr_2O_7 \times \text{Volume of } K_2Cr_2O_7}{\text{Blank titre}}$$

Organic carbon (OC) (g/kg) = OC (%) ×10

3.6.3 The carbon stock (SOC) in each agro ecological system was calculated with the formula = C (gkg^{-1})/100 × soil bulk density × area (1 ha) × soil depth. Soil organic carbon

(SOC) stock was determined as a product of soil carbon of each depth, multiplied by depth, bulk density and $10000m^2$ and divided by 1000 i,e.,

SOC= Org (C × D × BD × 10000)/1000 (t C ha^{-1}) where d = C = organic carbon concentration (gkg^{-1}) Bd = bulk density at the depth (Mgm^{-3}depth).

Where SOC = carbon stock of soil (t C ha^{-1}) Org), $10,000m^2$ =1ha, and 1000kg=1ton. Anikwe (2003)

3.6.4 Exchangeable bases (Ca, Mg, K, and Na)

Exchangeable Bases (Ca, Mg, K and Na): Exchangeable Ca, Mg, K and Na were extracted in ammonium acetate (1N NH4OAC) solution using 1:10 soil to solution ratio according to Agbenin (1995). Calcium (Ca) and Magnesium (Mg) were determined by EDTA titration method (Agbenin, 1995). Potassium (K) and Sodium (Na) were determined using flame photometry (Anderson and Ingram, 1993).

3.6.5 Cation exchange capacity (CEC)

The cation exchange capacity (CEC) was determined after extracting the soil samples by ammonium acetate (1N NH4OAc) at pH 7.0,

3.6.6 Total Nitrogen

The total nitrogen determination was done using macro kjeldahl method as described by Bremner (1982).This involves mixing of 10 ml distilled water inside a 500 ml kjeldahl flash, 3 g of Kjeldahl catalyst, 15ml of concentrated H_2SO_4 and soil sample. This was heated and later mixed with 75 ml of 10 M of NaOH and granular Zinc. The digest was distilled and about 50 ml of the distillate was collected which was then titrated with 0.05 M H_2SO_4 to pink end point. The nitrogen content was calculated by the formula:

$$N\% = \frac{0.014\times(\text{Titre value} - \text{Blank titre value})\times NA\times\text{Vol. of digest}\times 100}{\text{Weight of soil}\times\text{Aliquot taken}}$$

Where NA = Concentration of acid used

N (g/kg) = N (%) ×10

3.6.7 Available phosphorus was determined by Bray-1 extraction method (Bray and Kurtz, 1945).

3.6.8 Electrical conductivity (EC) was determined using conductivity Meter Bridge at 1:5 soils: water ratio. The reading was multiplied by 6.4 (Landon, 1991) to obtain electrical conductivity (EC dS/m) of the soils

3.7 Soil quality evaluation

Soil quality evaluation was based on the soil management assessment framework (SMAF) suggested by Andrews *et al*. (2004), scoring functions for 14 potential soil quality indicators (Wienhold *et al*., 2009). A general guideline has been the use of minimum of five indicators with at least one each for biological, chemical and physical properties or process (Karlen *et al*., 2011) as suggested by Larson and Pierce (1992); a minimum data set (MDS) was established. The MDS selected in this study include soil functions such as ease of tillage, salinity support for plant growth, bulk density (BD), CEC, total N, available P, and exchangeable K were used as indicators for plant growth support, while organic carbon was indicator for biological activity in the soil and MWD to assess erodibility of the soils. Indicators were divided into three, more is better was applied to N, P, K and organic matter, while less is better which applied to bulk density, optimum is better which applied to pH (Larson and pierce 1994).

3.7.1 Indexing soil quality indicators

This is due to temporal and variability of soil, complexity of an ecosystem and differences in soil management practices available. Andrews *et al.,* 2001 postulated that once the system s management goal are identified, soil quality indexing involve three main step

1. Choosing appropriate soil quality indicator for minimum data set
2. Transforming indicators score
3. Combining indicators the scores into the index.

3.7.2 Choosing appropriate soil quality indicator for minimum data set

The important step in indexing soil quality indicators is to choose appropriate soil quality indicators to efficiently and effectively capture the effect of critical soil functions as determined by management goal for which the evaluation is being made. Larson and pierce, (1994) proposed a minimum set of data, which is the smallest set of soil properties or indicators needed to measure soil quality, identifying key soil properties or attribute that are sensitive to change in soil functions established a minimum data set

Table 3 show Soil quality indicators selected for minimum data set and its function

Indicators of soil condition	**Relationship to soil condition and function**
	physical
Texture	Retention and transport of water and chemical,
Bulk density and infiltration	Potential for leaching ,productivity and erosivity
Water holding capacity	Related to water retention ,transport and erosivity, available water texture and organic matter
	chemical
Soil organic matter	Fertility and stability
pH	Biological and chemical activity threshold
Electrical conductivity	Plant and microbial activity
Extractable N, P, and K	Plant loss available and for N
	biological
Microbial biomass C and N	Microbial catalytic
Potentially mineralization	Soil productivity and N supplying potential
Soil respiration, water content and temperature	Microbial activity

(Larson and Pierce, 1992).

3.7.3 Transforming indicators score

This involve selecting MDS for assessing a particular management objective, Karlen *et al.*,(2001) explained that this step is required so that biological, chemical and physical indicator measurement with totally different measurement unit can be combined. Andrew and Carol, (2001) emphasized simplicity of design and use by developing a linear scoring techniques that relies on the observed of data to determine the highest possible score for each indicator and non- linear score technique involve the use of curve linear scoring functions with a y-axis ranging from 0 to one and x axis representing a range of site of function

a) More is better: total nitrogen, cation exchange capacity organic carbon content microbial biomass
b) less is better: bulk density
c) optimum is better: porosity electrical conductivity, water filled pore space phosphorus, pH, would electrical conductivity Anikwe (2006)

3.8 Statistical Analysis

Analysis of variance (ANOVA) test was done to determine significant difference among treatments. In conditions where there was significant difference, mean comparison was performed with least significant difference (LSD) at 0.05% level of probability using statistical analysis software (SAS) SAS, (1997). Correlation analysis was also used to determine level of relationship between soil properties of the slopes and the land uses.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effects of land use and slope on soil physical properties

4.1.1 Dry means weight diameter (dmwd)

Forestland had mean dry aggregate fractions of 1.24 mm; while cultivated land had 1.19 mm cultivated land has 1.22 mm, 1.04 mm and 1.32 mm for upper, middle and lower slopes. Similarly, forestland had 1.21 mm, 1.18 mm and 1.31mm for upper, middle and lower slopes respectively depth of 0 -10 cm (Table 4.1). This implies a negative impact of tillage on aggregate size distribution when compared with values in forest land use. Dry aggregate size distribution is one of the major physical characteristics of soil that strongly affects soil quality, fertility and its resistance to erosion and degradation and is also considered an indicator of soil structure (Odunze *et al.*, 2013).

The high proportion of large macro-aggregates and macro-aggregates fractions in Afaka plantations might be attributed to addition of litter materials and the symmetrical nature of plant root with lateral roots positively aiding aggregate stability through additional cohesion of soil particles (Odunze, 2012). Exudates from tree roots and microbial excretions into the soil might have also aided aggregation process by acting as cementing agents (Haynes and Francis, 1993). This result supports earlier findings of Ogunwole and Ogunleye (2004), who reported 11 % increased turnover of macroaggregates under *Jatropha curcas* L （JCL) plantation on a degraded Indian Entisol over native vegetation. The possible reason for this high value may be associated with high amounts of divalent cations which accompany applications of manure and inorganic fertilizer. The implication of this is that land with highest mean value of dry MWD will have better stable aggregates that can withstand wind erosion than other treatments, while those with low mean values may be most vulnerable to wind erosion due to low dry stable aggregates (Ogunwole and Ogunleye, 2004). Increasing intensity of cultivation can reduce carbon

Table 4.1 Effects of Land Use and Slope on Dry and Wet Mean Weight Diameter, Particle Size, and Silt/Clay

	dmwd	wmwd	Sand%	Silt%	Clay%	Textural class	Silt /clay
Land use							
forest	1.19	1.19	71.11	14.89	14.00	sandy loam	1.06
cultivation	1.24	1.27	67.11	19 .11	13.78	sandy loam	1.3
SE<u>+</u>	0.08	0.12	2.1	1.5	0.83		
Cultivated slope							
upper	1.22	1.00	69.33	17.33	13.3	sandy loam	1.3
middle	1.04	1.51	64.66	21.33	14.00	sandy loam	1.5
lower	1.32	1.05	67..33	18.66	14.00	sandy loam	1.3
Forest slope							
upper	1.21	1.36	74.00	13.33	12.66	Sandy loam	1.05
middle	1.18	1.04	70.00	16.00	13.33	Sandy loam	1.2
lower	1.31	1.36	68.66	16.33	15.00	Sandy loam	1.08
SE<u>+</u>	0.10	0.15	2.51	1.8	1.02		

DMWD = dry mean weight diameter, WMWD = wet mean weight diameter rich macro-aggregates and increase carbon depleted micro-aggregates, resulting in an overall loss of soil organic carbon (Six *et al.,* 2000). Conventional ploughing; which is commonly practiced in Afaka areas, causes damage to soil structure. Noellemeyer *et al.* (2008) reported a loss of intermediate aggregate size classes after long term cultivation with more pronounced negative effects of cultivation on macro aggregate size classes. This finding supports that the conversion of native forest to cultivation leads to deterioration of soil structure (Tisdall and Oades, 1980) as was applicable to Alfisols in Afaka forest reserve in Northern Guinea savanna of Nigeria.

4.1.2 **Wet mean weight diameter (WMWD)**

.Cultivated land recorded 1.19 mm; which was lower than forested land with 1.26mm. Similarly, cultivated land recorded 1.00 mm, 1.51 mm and 1.05 mm for upper, middle and lower slopes while forest recorded 1.36 mm, 1.04 mm and 1.36 mm for upper middle and lower slopes respectively at depth of 0-10cm (Table 4.1). The mean water stable aggregates were highest at forest than cultivated land though not statistically significant ($p > 0.05$). The low wet MWD recorded in cultivated land may be associated with degradation of large macro-aggregate fractions in the dry soil when immersed in water (Unger, 1997), a situation consistent with natural wetting by intense rain. Perhaps, soil amendments used (Farmyard manure and inorganic fertilizer) by farmers may account for this soil improvement index. Denef *et al.* (2001) reported that stability of wet aggregates can be related to surface seal development and field infiltration, as water-stable cohesion among particles may lead to restriction of water entry and formation of surface seals. Generally, additions of organic material in the form of either farmyard manure or through the decomposition of plant residue over long periods of time play a significant role in the stability of aggregates in water or wind. This improves the soils capability for withstanding water erosion (Ogunwole and Ogunleye, 2004).

4.1.3 Particle size distribution

The mean values for sand, silt and clay fractions for forest field were 71.11 %, 14.89 %, 14.00 % and cultivated fields 67.11 %, 19.11 %, 13.78 % respectively. Upper slope had the highest sand content (74.00 %), followed by middle (70.00 %) slopes, then lower slope with (68.67 %) in forestland, while cultivated land had 69.33 %, 64.66 % and 67.33 % for upper, middle and lower slopes respectively. Middle slope had the highest silt content (21.33 %) followed by lower slope with 18.66 %, while upper slope had 17.33 % values in cultivated land. Silt content in forest at lower slope position was 16.33 % and 16.00 % at middle and upper slope positions respectively. The soil clay content of 15.00 % was observed at lower slopes in forestland; 13.33 % was observed at the middle slope, while upper position had 12.00 % clay content. Also, 14.00 % each of clay was observed in both middle and lower slopes while 13 % was observed at upper slope in cultivated land, with classes as sandy loam texture (Table 4.1). Particle sizes were not different significantly (p>0.05) for the two land uses and slopes this suggests that the soil texture was not affected by conversion of forest to cultivated land use and could be prone to leaching due to the high presence of macro-pores of dominating sand fraction that would not affect growth of crops due to low moisture and nutrient retention capacity (Brady and Weil, 2002). Despite the fact that texture is an inherent soil property, management practices may contribute indirectly to changes in particle size distribution particularly in the surface layers as a result of removal of soil by sheet and rill erosions, and mixing up of surface and subsurface layers during tillage activities. Therefore, significant differences in particle size distribution attributed to impact of deforestation and farming practices; such as continuous tillage or cultivation, can be observed over a long time. In this study, there were no significant differences in particle size distribution along different topographic positions of the soils under different land use types. Clay content increased as slope gradient lowers, while sand content showed a decreasing trend down slope. This was most probably due to removal of fine soil particles by erosion from the upper slope, while deposition of these particles occurred on the lower slope positions. According to USDA system of soil texture classification (USDA, 1987), soils under gently sloping area had sandy clay at depth of 0-10 cm, while other soils of the study area were categorized under sandy clay loam textural class. Most field crops could grow well in such soils having sandy clay and sandy clay loam textural classes at the depth of 0-10 cm, as these soils have potentially well-balanced capacity for crop production and to retain water, form stable structure and provide adequate aeration (USDA, 1987). USDA (1987) reported that sandy loam textured soil governs most properties of soils; such as permeability, capacity to retain water, degree of aeration, ability to make nutrients stored in clay–humus complex available to plants. This may be because in cultivated land use, continuous cultivation facilitates movement of particles from one place to another (from higher to lower position) and results in deposition of particles by erosion, especially at lower position.

4.1.4 Silt /clay ratio

Silt/clay ratios are relatively higher in cultivated land with 1.3 silt/clay ratios and decrease with 1.06 silt/clay ratios in forestland Van Wambeke (1962) reported that “old” parent materials usually have silt/clay ratio below 0.15, while silt/clay ratios above 0.15 are indicative of “young parent materials. The result of this study shows that, all the soils had silt/clay ratios above 0.15, indicating that the soils had high degree of weathering potentials (Table 4.1). Suggesting that soils under cultivated land use were more recent deposits; perhaps resulting from colluviation and surface wash of disturbed soils. The decrease in silt/clay ratio with depth indicates that sub soils were more weathered than surface soil. The soils were considered to be moderately weathered as mean values of silt/ clay ratio of all the soils were higher than the 0.15 critical threshold considered to be highly or intensively weathered (Van Wambeke, 1962; Yakubu and Ojanuga, 2009).

4.1.5 Bulk density

The highest BD was under cultivated land at depths 0-5 cm (1.49 Mg m^{-3}) followed by 5-10 cm (1.46 Mg m^{-3}), under forestland. In contrast, the low BD values at 0-5 cm (1.42 Mg m^{-3}) and 5-10 cm (1.34 Mg m^{-3}) were observed under forestland. The mean value for slopes at 0-5 cm depth was 1.43 Mg m^{-3}, 1.46 Mg m^{-3} and 1.36 Mg m^{-3} for upper, middle and lower slope positions respectively in cultivated land, while mean value for slopes at 5-10 cm depth was 1.40 Mgm^{-3}, 1.40 Mg m^{-3} and 1.23 Mg m^{-3} for upper, middle and lower slope positions respectively in cultivated land. Forest land had mean value for slopes at 0-5 cm depth as 1.50 Mg m^{-3}, 1.46 Mg m^{-3} and 1.50 Mg m^{-3} for upper, middle and lower slope positions respectively, while mean value for slopes at 5-10 cm depth was 1.53 Mg m^{-3}, 1.43 Mg m^{-3} and 1.40 Mg m^{-3} for upper, middle and lower slope positions respectively, results of soil analyses on bulk density (BD) of different land use and slope are presented in Table 4.2. High bulk density under cultivated lands was attributed to trampling effects, continuous cultivation and soil surface sealing/ crusting. Odunze

(2012) observed that bulk density rapidly increased with depth in the surface, but remained uniform at depths >20 cm and bulk densities tend to increase with depth primarily due to lack of organic matter and aggregation. Islam and Weil (2000) observed that Forestland had lower bulk density than cultivated land and attributed it to restricted movement of machine at the forested land compared to continuous cultivation of the cultivated land. Forest litter and roots' decompose over time to improve quality of surface soils and reduce bulk density. Evrendilek *et al*. (2004) also reported that conversion of forestland into cultivated land during a 12-year period increased bulk density and decreased total porosity. Perhaps, Forestland had higher organic matter (OM) content; making the soil loose, porous and well-aggregated, that might have reduced soil bulk density. The result also shows that bulk densities decreases with slope. The variation of soil bulk density among slope

Table 4.2 Effects of Land Use and Slope on Bulk Density, Particle Density, Porosity and Hydraulic Conductivity

	Bulk density (Mg m^{-3}) 0-5cm	(Mg m^{-3}) 5-10cm	PD (Mg m^{-3})	POROSITY (%)	Hydraulic (cm h^{-1}) 0-5cm	(cm h^{-1}) (5-10cm
Land use						
forest	1.42^{a}	1.34^{a}	2.44^{a}	40.77^{a}	3.07^{a}	3.41^{a}
cultivation	1.49^{a}	1.46^{a}	2.48^{a}	46.10^{a}	2.82^{a}	2.79^{a}
SE±	0.05	0.06	0.04	2.3	0.7	0.6
Cultivated slope						
upper	1.43	1.40^{a}	2.59^{a}	47.36^{a}	2.5^{a}	3.5^{a}
middle	1.46	1.40^{a}	2.42^{b}	44.43^{a}	2.4^{a}	2.3^{a}
lower	1.36	1.23^{a}	2.44^{ab}	46.5^{a}	2.3^{a}	2.5^{a}
Forest slope						
upper	1.50	1.53^{a}	2.57^{a}	42.8^{a}	4.6^{a}	4.8^{a}
middle	1.46	1.43^{a}	2.35^{a}	36.3^{a}	2.9^{a}	3.7^{a}
lower	1.50	1.40^{a}	2.44^{a}	43.16^{a}	1.6^{a}	1.5^{a}
SE±	0.06	0.06	0.01	2.8	0.80	0.79

BD = Bulk density 0-5 and 5-10 cm, PD = particle density, Ksat = hydraulic conductivity gradients might be attributed to variation of disturbance of soil particles by erosion. Suspended finer particles were transported down the slope where they accumulate at the bottom; thus increasing clay and silt content at the bottom slope positions with higher micro porosity and lower bulk density (Midkiff *et al.*, 1985).

4.1.6 Particle densities

Forest land had means of 2.44 Mg m^{-3} while cultivated land had 2.48 Mg m^{-3} respectively. Particle density of 2.59 Mg m^{-3}, 2.42 Mg m^{-3} and 2.44 Mg m^{-3} were recorded for upper, middle and lower slopes respectively in cultivated land and 2.57 Mg m^{-3}, 2.35 Mg m^{-3} and 2.44 Mg m^{-3} were recorded for upper, middle and lower slopes respectively in the forestland (Table 4.2). Particle density land use and slope was not significantly differ at >0.05. The finer soil particles were selectively removed by erosion, thereby increasing proportion of coarser particles and leaving more sand particles (Ayoubi *et al*., 2011). Soils with higher proportion of sand particles have higher particle density (Brady and Weil, 2002). Particle density increased with depth and could be due to reduction of soil organic matter (OM) with increasing depth.

4.1.7 Porosity

The values of total porosities of 46.10 % were at depth of 0-10 cm in cultivated site, whereas values of 40.77 % was obtained at depth of 0-10 cm in forested land, mean values of 46.5 %, 44.4% and 47.36 % were obtained for upper, middle and lower slopes respectively in cultivated land, while mean values of 42.8 %, 36.3% and 43.16 % were obtained for upper, middle and lower slopes respectively in the forestland (Table 4.2) were statistically similar. Porosity decreased with slopes, which could be due to reduction of soil organic matter (OM) with decreasing slope steepness or length. The lowest total porosity recorded in moderately steep middle slope cultivated was attributed to surface wash by erosion and exposure of sub soil layers , high bulk density, low clay content and low organic matter content (Table 4.2) at this geomorphic position. According to FAO (2006), rating of total porosity values in all slope gradients were high (greater than 40 %), indicating that the study area soils were mostly within the 40 to 50 percent rating for good agricultural soils (FAO, 2006).

4.1.8 Hydraulic conductivity (Ks)

Table 4.2 shows value of saturated hydraulic conductivity (Ks) under different land use types. Forest land Ks was 3.07 cm h^{-1} at depth of 0-5 cm and 3.40 cm h^{-1} at depth 5-10 cm. On cultivated land, Ks were 2.82 cm h^{-1} at depth 0-5 cm and 2.79 cm h^{-1} at depth of 5-10 cm similarly upper, middle and lower slopes for cultivated land had means of 3.6 cm h^{-1}, 2.4 cm h^{-1} and 2.3 cm h^{-1} for 0-5 cm, while 3.5 cm h^{-1}, 2.3 cm h^{-1} and 2.5 cm h^{-1} for upper, middle and lower slopes at 5-10 cm respectively. Similarly, upper, middle and lower slopes for forestland had means of 4.6 cm h^{-1}, 2.9 cm h^{-1} and 1.6 cm h^{-1} for 0-5 cm, while 4.8 cm h^{-1}, 3.7 cm h^{-1} and 1.5 cm h^{-1} were for upper, middle and lower slopes at 5-10 cm respectively (Table 4.2). This might be due to increased bulk density with depth as observed by Ohu *et al*. (1989). Also increase in clay content with depth would cause clay particles to clog conducting pores and decrease saturated hydraulic conductivity (Okai, 2001). The value of Ks was extremely low at lower slopes, perhaps due to nature of clay and soil compaction. Comparison of the two land uses showed that hydraulic conductivity at top soils of forestlands was significantly higher than in cultivated soils. This might be due to difference in clay, organic matter content, surface sealing/crusting and soil compaction at cultivated sites. Hydraulic conductivity was similar in interaction between location and slopes. Overall, these findings agree with results reported by Jabro *et al*. (2009) that greater Ks values correspond with lower soil bulk density values at the subsurface depth

4.1.9 Available moisture content

Available moisture content was determined at two depths (0-5 cm and 5-10 cm). Result shows that forest retained highest moisture content of 4.20 cm^3/cm^3 at 0-5 cm and 4.32 cm^3/cm^3 at 5-10 cm, while the lowest moisture content of 2.82 cm^3/cm^3 at 0-5 cm and 2.79 cm^3/cm^3 at 5-10 cm were observed under cultivated land (Table 4.3). The cultivated land had mean values of 1.3 cm^3/cm^3, 4.2 cm^3/cm^3 and 2.3 cm^3/cm^3 for upper, middle and lower slope respectively at the depth of 0-5cm whereas 1.6 cm^3/cm^3, 4.2 cm^3/cm^3 and 1.5 cm^3/cm^3 at 5-10 cm for upper, middle and lower slopes at depth of 5-10 cm respectively. Forestland recorded 4.03 cm^3/cm^3, 4.5 cm^3/cm^3 and 4.06 cm^3/cm^3 for upper, middle and lower slopes respectively at 0-5 cm similarly, 4.06 cm^3/cm^3, 5.53 cm^3/cm^3 and 3.36 cm^3/cm^3 at depth of 5-10 cm for upper middle and lower slope respectively and were significantly different ($P < 0.05$). The interaction result shows that middle slope forest record high with 4.50 cm^3/cm^3 fallow by middle slope cultivated but statistically similar with lower and upper slope forest, but significantly different for upper and lower slope cultivated (Table 4.3b). This confirms that cultivation deteriorates soil structural aggregation and reduces soil water retention capacity (Wakene, 2001). Soil moisture content at field capacity (FC) for all land use systems show decrease in trend with depth (Wakene, 2001). Considering land uses on different topographic positions, greater water retention at forestland was observed in soils of middle slope positions. This difference in moisture content was attributed to effect of soil type, position on topography and organic matter content. Total available water was highest in natural forestland (Table 4.3). Higher clay and organic carbon (OC) provided large surface area required for absorption and retention of water molecules (Materechera and Mkhabela, 2001). Natural forest soils have more available water holding capacity compared to cultivated lands (Ayoubi, 2011).

Table 4.3 Effects of Land Use and Slope on Available Moisture Content Electrical Conductivity, pH, $CaCl_2$ and Organic Carbon

Land use	AWC(0-5) (cm^3/cm^3)	AWC(5-10) (cm^3/cm^3)	EC (dSm^{-1})	pH (H_2O)	pH ($CaCl_2$)	OC (g/ kg)
forest	5.96	5.79	0.13	7.16	6.49	10.2
cultivation	3.17	3.84	0.12	6.90	6.22	8.2
SE±	0.2	0.33	0.02	0.1	0.12	0.1
Cultivated slope						
upper	1.3	1.6	0.08	6.9	6.13	8.7
middle	4.2	3.2	0.12	6.9	6.16	9.6
lower	2.3	1.5	0.15	6.8	6.36	6.3
Forest slope						
upper	4.03	4.06	0.06	7.2	6.5	6
middle	4.5	5.53	0.16	6.9	6.3	12.4
lower	4.06	3.36	0.17	7.2	6.6	12.3
SE±	0.28	0.03	0.03	0.12	0.14	0.13

AWC = Available moisture content, EC = Electric conductivity, OC = organic carbons, NS = not significant, value without letter ascribe to are statistically the same.

Table 4.3.1 Effects of land use and slope on available moisture content (cm^3cm^{-3})

	Land use	
Slope	**Forest**	**Cultivated**
lower	4.07	2.33
middle	4.50	4.20
upper	4.03	1.37
SE±	0.64	

4.2 Effects of land use and slope on soil chemical properties

4.2.1 Electrical conductivity (EC)

Electrical conductivity values were 0.13 dS/m in forest, and 0.12 dS/m for cultivated land, though statistically not different. Electrical conductivity was significantly affected by slopes. Upper slope had the mean of 0.15 dS/m; middle slope had 0.12 dS/m and lower slope has 0.08 dS/m in cultivated land. Similarly Forestland electrical conductivity at upper slope had the mean of 0.17 dS/m; middle slope had 0.16 dS/m and lower slope 0.06 dS/m respectively. Electrical conductivity (EC) below 0.75 dS/m is considered low; 0.75–4 dS/m is medium and above 4 dS/m is considered high (McCulley *et al*, 2005). Lower slopes had less electrical conductivity value, but show increasing trend in soil EC down the slope for cultivated land use type (Figure 4.3). Soluble cations and anions also moved down the slope with surface runoff and accumulate at the bottom slope. The work of other researchers (Putman *et al*., 1987; Ahmad and Khan, 2009) confirmed increase in EC with depth, which they presumed was due to downward movement of soluble ions (Na^+, K^+, Mg^{2+}, Cl-, and HCO^{3-}). Generally, electrical conductivity values recorded in soils of the different land use types on different topographic positions of study area were not in the range that could cause harm to growth of most crop plants. In addition, the generally low electrical conductivity values could be attributed to intense leaching process, which removes base-forming cations from crop root zones in soil.

4.2.2 Soil pH (H_2O) and $CaCl_2$

The highest soil pH in water (pH 7.16) was recorded in forestland and pH 6.9 in cultivated land.

The upper slope had pH (H_2O) 6.9, middle slope had pH (H_2O) 6.9 and lower slope had pH (H_2O) 6.8 in cultivated land, while forestland had pH (H_20) 7.2, 6.9 and 7.2 for upper, middle and lower slopes respectively. Values of soil pH ($CaCl_2$) were 6.49 and 6.22 for forest and cultivated land use types respectively. Upper slopes had pH ($CaCl_2$) 6.13; middle slope had pH ($CaCl_2$) 6.16 and lower slope had pH ($CaCl_2$) 6.36 in cultivated land, while 6.5 pH ($CaCl_2$), 6.3 pH ($CaCl_2$) and 6.6 pH ($CaCl_2$) values were recorded in forest land (Table 4.3). It however increased slightly down the topographic positions in soils of both cultivated and forested lands. The generally increasing trends in pH value from middle to lower slope positions may be due to higher deposition of basic cations in lower slope positions. This agrees with Belay (1996), Abayneh (2001) and Mohammed *et al*. (2005) who independently reported low pH value in soils of high altitude and steeper slopes are associated with washing out of solutes from these parts. The soil pH range of 6.9 to 7.16 indicates moderately acidic to alkaline soil condition under all the land use systems. Malo *et al*. (2005) also reported that increase in pH with soil depth could be associated with enhanced carbonate levels and less weathering rates. The pH of study soils may also indicate low level of leaching of non-acid cations (Adeboye, 2009). The relatively higher pH value recorded under natural forest land use type could be attributed to higher amount of basic cations; especially Ca and Mg and higher amount of organic matter contents. The lowest pH value recorded in soils of cultivated land use type could be due to continuous removal of basic cations by crops, intensive cultivation that enhanced leaching of basic cations, application of inorganic fertilizers and washing away of exchangeable bases by rill and sheet erosion. Mokwunye (1978) indicated that continuous cultivation and application of inorganic fertilizers on a long-term basis lowers pH and aggravates loss of basic cations from highly weathered soils.

Soil pH in water increased at the bottom slope position was attributed to accumulation of bases that were eroded (colluvium) from the top slope positions (Garcia *et al*., 1990; Hendershot *et al*., 1992). Increase in soil pH down the slope could be attributed to downward movement of Calcium and accumulation in the middle and lower slopes. Researches reported a sharp increase in soil pH with increasing soil depth (Webb and Dowling, 1990; Khan *et al*., 2004) due to higher accumulation of Ca^{2+} in the sub-surface soil (Kaihura *et al*., 1999). Hao and Chang (2003) reported similar results and revealed that in irrigated soils, Ca^{2+} decreased in surface soil (0-15 cm) but increased at depths below 30 cm due to downward movement of lime to subsurface soil that cause increase in soil pH.

4.2.3 Organic carbon (OC)

Organic carbon (OC) concentration varied under the different land use systems at 0-10 cm depth. Cultivated land had mean of 8.2 g /kg while forestland had 10.2 g/ kg. Organic carbon concentration was higher at the middle and lower slopes than upper slope with the mean of 6 g/ kg, 12.4 g/ kg, and 12.3 g/ kg for upper, middle and lower slopes respectively in the forestland, while cultivated land had mean of 8.7 g/kg, 9.6 g/kg and 6.3 g/kg for upper, middle and lower slope respectively (Table 4.3). The organic carbon in forestland might be due to accumulation of plant roots, deposition of plant litter and limited soil disturbance that aided accumulation of organic carbon. Other findings corroborating this report include Odunze (2006), who observed highest organic carbon in forest soil, followed by lowest under agro-ecosystems. Conversion of forest ecosystem to other forms of land cover may decrease stock of OC due to changes in soil moisture, temperature regimes and succession of plant species with differences in quantity and quality of biomass returned to the soil (Offiong and Iwara, 2012). Results of the present study were in contrast to Woldeamlak and Stroosnijder, (2003), who obtained relatively higher content of both organic carbon and total nitrogen from cultivated land use systems than that of forestlands and attributed higher concentration of total nitrogen under cultivated land use systems to higher organic matter content as a result of manure addition; implying that increased organic carbon increases total nitrogen. However the decrease of SOC was gradual in cultivated lands when compared to virgin forestland; may be due to disturbances by tillage implements, which could mix different soil layers. In line with this, Gregorich *et al*. (1995) observed that concentration of organic carbon (OC) in forest soil decreased with depth by more than 10-fold in the surface 30 cm, from 139 g/kg soil in the 0-15 cm layer to 12 g/kg soil in the 15-30 cm layer.

4.2.4 Carbon stock:

The study of carbon stock (SOC) shows that there were differences in total quantity of carbon stock in different land utilization types in the study area (Table 4.4). Results show forestlands with quantity of carbon stock of 1522.1 C kg/ha and cultivated land with 1124.3 C kg/ha at 0-10 cm soil depth. Cultivated land has 885.1 C kg/ha, 1397.4 C kg/ha and 1090.4 C kg/ha for upper, middle and lower slope respectively. However, forest record 1959.2 C kg/ha, 1742.2 C kg/ha and 867.9 C kg/ha respectively (Table 4.4). These findings corroborate Anikwe *et al.,* (2003) and Krull *et al.* (2001), who showed that tillage adversely affected carbon storage in soils. The quantity of carbon stored in natural forest was greater than that of cultivated land, partly because of time interval of forestation, greater diversity and age of plant species found at Afaka forests. Evrendilek *et al*. (2004) noted that deforestation and subsequent cultivation decreased soil organic matter content. Also, conversion of forest into cropland deteriorates soil physical properties and makes land more susceptible to erosion, since macro-aggregates are disturbed (Çelik, 2005). Organic carbon is a good indicator for assessing soil potential productivity (Shukla *et al*., 2006). This finding suggests that continuous cultivation should be discouraged since it reduces carbon contents due to reduced tree cover and increased mineralization due to surface disturbance for sustainable agricultural land use in Afaka area. Conservation tillage systems; such as no-till with cover crops, reduces soil disturbance and managed residue for increased soil organic matter and improved soil aggregate stability (Lal, 1997a).

Table 4.4: Effects of Land Use and Slope on Carbon Stock, Total Nitrogen, Available Phosphorus, Carbon/Nitrogen and Ratio Exchangeable Sodium Concentration

	SOC (C kg ha^{-1})	TN (g kg^{-1})	AP (mg kg^{-1})	C/N	Na (cmol kg^{-1})
Land use					
forest	1522.1	1.2	8.78	8.5:1	0.44
cultivation	1124.3	1.1	5.4	7.5:1	0.45
SE$\underline{+}$	132.58	0.01	2.1		0.04
Cultivated slope					
upper	885.1^{c}	1.1	9.60	7.9:1	0.43
middle	1397.4^{ab}	1.4	3.2	6.8:1	0.51
lower	1090.4^{a}	0.9	13.4	7.0:1	0.41
Forest slope					
upper	1959.2^{a}	1.4	8.82	4.3:1	0.39
middle	1742.2^{ab}	1.4	5.01	8.8:1	0.48
lower	867.9^{c}	0.9	2.45	13.6:1	0.43
SE$\underline{+}$	229.64	0.41	2.57		0.05

SOC = soil organic carbons stock, C/N = carbon/nitrogen ratio, TN = total nitrogen, AP= available phosphorus, and Na = sodium concentration.

4.2.5 Total nitrogen

Total N contents were highly affected by the different land use systems. Total soil nitrogen at 0-10 cm depth had mean of 1.11 g kg^{-1} under cultivated land, while 1.2 g kg^{-1} was recorded under natural forest land,

cultivated land had mean of 0.9 g kg^{-1}, 1.4 g kg^{-1} and 1.05 g kg^{-1} of total nitrogen for upper, middle and lower slopes respectively, while forestland had mean of 1.4 g kg^{-1}, 1.4 g kg^{-1}and 0.9 g kg^{-1} total nitrogen in upper, middle and lower slopes respectively (Table 4.4). Iwara *et al*. (2011) reported that presence of dense vegetation affords the soil adequate cover, thereby reducing loss in macro and micro nutrients that are essential for plant growth and energy fluxes. The total nitrogen status was low in cultivated land and high under natural forest land use in Afaka northern guinea savanna of Nigeria. Ayoubi *et al*. (2011) reported that natural forest soils had more total nitrogen compared to cultivated lands. Heluf and Wakene (2006) reported highest total N on surface soil layers of virgin lands compared to cultivated and farmers' fields. Total nitrogen decreased consistently with depth under land use systems corresponding to the findings of Gong *et al*. (2005), Geissen and Guzman (2006) and Alemayehu (1990).

4.2.6 Available phosphorus (AP)

Available phosphorus (AP) concentration of land use systems had mean values of 8.78 mg kg^{-1} and 5.47 mg kg^{-1} for forest and cultivated land, Lower slopes recorded 13.4 mg kg^{-1} available phosphorus, followed by upper slope with 9.60 mg kg^{-1} and middle slope with 3.2 mg/kg in cultivated land. Forestland at upper slopes recorded 8.82 mg kg^{-1} available phosphorus, followed by middle slope with 5.01 mg kg^{-1} and lower slope with 2.45 mg kg^{-1} in (Table 4.4). Thomas (2000) reported that natural forestland contained relatively higher concentration of AP as a result of high organic matter turnover in soils, which released phosphorus during its mineralization and is in conformity with findings from this study. The difference in available phosphorus might be due to increased clay and reduced organic matter concentration in cultivated land. Organic compounds in soils increase P 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 phosphorus fixation (Thomas, 2000). Also, decomposing of organic matter releases acids that increase solubility of calcium phosphates (Ahn, 1993; Thompson and Troeh, 1993; Havlin *et al.*, 1999). Available P was positively correlated with organic carbon (Thomas, 2000).

Differences of slope gradient among the areas did not significantly ($P > 0.05$) affect available P (Table 4.4). The lowest (4.12 mg kg^{-1}) and highest (9.31 mg kg^{-1}) contents of available P were recorded in soils of middle slope and upper slope terrains respectively (Table 4.4). Fisseha *et al.* (2014) also reported low available P within soils having low content of OM, but Nega and Heluf (2013) stated that available P content of Tropical soils did not necessarily decrease with decrease of organic matter. The low contents of available P observed in soil of the study area were in agreement with reports by some authors (Murphy and Lugo, 1986; that availability of P under most soils of savanna Alfisols decline by the impacts of fixation, abundant crop harvest and erosion.

4.2.7 Carbon/Nitrogen ratio

In this study, carbon to nitrogen (C/N) ratio was affected by land use systems. Consequently, the ratio was narrower in soils of cultivated lands with 7.5:1 C: N ratio when compared with forestland with 8.5:1 C: N ratio. Cultivated land had 7.9:1, 6.8:1 and 7.0:1 of carbon nitrogen ratio for upper middle and lower slope while forest land record 4.3:1, 8.8:1 and 13.6:1carbon nitrogen ratio for upper, middle and lower slope respectively (Table 4.4). This is in agreement with Seeber and Seeber (2005), who reported that cultivation alters humus content and thus narrows the C/N ratio. Such differences in C/N ratios among land use systems may also reflect variations in qualities of organic residues entering the soil organic matter pool and could be attributed to contrasting vegetation covers. Caravaca (2002) found lower C/N ratios in cultivated fields than uncultivated soils and ascribed the higher C/N ratios to input of relatively recent materials of plant or microbial origin in non-cultivated soils. The present study is also in agreement with findings of Odunze (2006), which reported greater C/N ratios in forest soils than agricultural soils. Similarly, Raji and Ogunwale, (2006) reported higher C: N ratio in forest soil as compared to soils under cultivation and pasture.

4.2.8 Exchangeable sodium (Na)

Exchangeable sodium (Na) varied in response to land use types, and slope aspects. Sodium values recorded were 0.44 cmol kg^{-1} and 0.45 c mol kg^{-1} for forest and cultivated land Upper, middle and lower slopes recorded 0.39, 0.48 and 0.43 cmol kg^{-1}, respectively in forestland, while cultivated land had 0.43, 0.51 and 0.41 cmol kg^{-1} for upper, middle and lower slopes respectively (Table 4.4). The concentration of Sodium was statistically similar; perhaps, due to erosion at the study area. Exchangeable Na; and K, did not show uniform increase or decrease in all land use types, topographic positions and slope aspects. Based on the critical level given by FAO (2006) < 0.10 cmol kg^{-1} very low, 0.1- 0.3 cmol kg^{-1} is low and > 2.0 cmol kg^{-1} very high, exchangeable Na of soils of the study area is low (Table 4.4)

4.2.9 Exchangeable cations:

Calcium had means of 4.92 cmol kg^{-1} and 4.87 cmolkg^{-1} for forest and cultivated land use systems. Magnesium was 2.11cmol kg^{-1} in the forest, while cultivated land had 2.01cmol kg^{-1} magnesium. Magnesium content significantly varied among slopes, means of 2.16 cmol kg^{-1}, 2.19 cmol kg^{-1} and 1.97 cmol kg^{-1} for upper, middle and lower slopes respectively in the forest, while cultivated land had means of 1.95 cmol kg^{-1}, 2.12 cmol kg^{-1} and 1.95 cmol kg^{-1} for upper, middle and lower slopes respectively (Table 4.5). Calcium was higher in middle slope, probably due to leaching, colluviation and eluviation-illuviation processes from upper slopes and in sub soils. Calcium was statistically similar in interaction between location and slopes. Calcium accumulated at the subsurface horizons may be accessible to tree species (Mokwunye, 1978). Gong *et al*. (2005) reported that depletion of organic carbon as a result of intensive cultivation reduced EC of soils under cultivated land use. In terms of plant nutrition, magnesium may not be a constraint in the study soils, but its accumulation in soil may have negative impact on soil structure and cause lower water intake rates that may affect chemical and biological properties of soil (Odunze, 2006). Potassium (K) varied in response to different land use types, and slope aspects. Potassium had means of 0.57 cmol kg^{-1}for forests and 0.40 cmol kg^{-1}for cultivated lands (Table 4.7). K means of upper slope was 0.59 cmol kg^{-1}, middle slope with 0.29 cmolkg^{-1} and 0.31 cmolkg^{-1} for lower slope cultivated land, while forestland had mean K values of 0.28 C molkg^{-1}, 0.81 cmol kg^{-1} and 0.63 cmolkg^{-1} for upper, middle and lower slopes respectively (Table 4.5).

Exchangeable K variations were not consistent in all land use types and slope; this may be due to the variations in intensity of weathering; intensive cultivations and use of acid forming inorganic fertilizers that affect distribution of K in soil systems to enhance its depletion (Saikh *et al*., 1998).

Table 4.5 Effects of land use and slope on exchangeable cation and cation exchange capacity

	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Al (cmol kg^{-1})	CEC (cmol kg^{-1})
Land use					
forest	4.92	2.11	0.58	0.14	8.60
cultivation	4.87	2.01	0.40	0.26	8.54
SE	0.37	0.04	0.09	0.03	0.5
Cultivated slope					
upper	4.03	1.95	0.59	0.33	7.93
middle	5.74	2.12	0.29	0.16	9.56
lower	4.84	1.95	0.31	0.26	8.13
Forest slope					
upper	5.74	2.16	0.28	0.10	9.00
middle	4.89	2.19	0.81	0.20	9.00
lower	4.12	1.97	0.63	0.13	7.80
SE±	0.45	0.05	0.11	0.04	0.60

Note: Calcium (Ca), magnesium (Mg), potassium (K) aluminum (Al) and cation exchange capacity (CEC)

According to FAO (2006) classification range (critical level range), <0.2 is very low, 0.2-0.3 is low and >1.2 is very high. Exchangeable K of soils of the study area was in the range of low to very high (Table 4.5). Data on exchangeable cations (Table 4.5) shows that in all soils, calcium was the dominating cation on exchange complex, followed by magnesium, sodium and potassium and occurred in the order of calcium>magnesium>sodium>potassium.

Aluminum content of the soil significantly varied among land uses. Forestland recorded lowest aluminum content (0.14 cmol kg^{-1}), while cultivated land recorded 0.26 cmol kg^{-1}; The aluminum values under cultivated land use type were 0.33, 0.16, and 0.26 cmol kg^{-1} for upper, middle and lower slopes while forestland had 0.10, 0.20 and 0.13 cmol kg^{-1} for upper, middle and lower slopes respectively (Table 4.5).

4.2.10 Cation exchange capacity (CEC):

Forestlands recorded CEC value of 8.60 cmol kg^{-1} compared to cultivated land with mean value of 8.54 cmol kg^{-1} while the lower slopes in forestland showed decrease in CEC with 7.80 cmol kg^{-1} and 9.00 cmol kg^{-1} for upper and middle slope respectively. The upper slope of cultivated land showed decrease in CEC with 7.93 cmol kg^{-1}, 9.56 cmol kg^{-1} for middle slope and 8.13 cmol kg^{-1} for lower slope (Table 4.8) as shown in Table 4.5. Cation exchange capacity (CEC) of soil is a very important indicator of soil fertility or at least of potential soil fertility, nutrient availability and could indicate the organic matter content of soil. There was variation in CEC of soils under the two land use types and slopes (Table 4.5). Cation exchange capacity (CEC) of the study area was not affected by land use. Woldeamlak and Stroosnijder (2003) reported higher CEC value in soils under natural forest than soils under cultivation. Bhaskar *et al.* (2005) reported lower CEC values obtained in cultivated land and could be partly attributed to erosion, nature of soils and low organic matter content of the soils.

4.3 Criteria for Soil Quality Monitoring and Evaluation in Afaka reserve, Nigeria

To monitor soil quality, treatment means for bulk density, mean weight diameter, pH in H_2O and $CaCl_2$, organic carbon, total nitrogen, available phosphorus, cation exchange capacity were matched as shown in the Table 4.6.

Bulk density shows that forest soil had the least bulk density 1.34 Mg m^{-3} while cultivated land had the highest bulk density 1.46 Mg m^{-3} (Table 4.6).

Table 4.6 shows that mean weight diameter dry for forest soil (1.24mm) is greater than for cultivated land (1.19mm). The pH in H_2O and $CaCl_2$ shows that pH decreased slightly under cultivation and increased under forest. Both pH in H_2O and $CaCl_2$ followed the same trend. Table 4.6 shows that there was increase in organic carbon contents under forest (10.2 g kg^{-1}) while cultivated land show decrease in organic carbon content (8.21 g kg^{-1}). Also, Table 4.6 shows that a total N content of (1.2 g kg^{-1}) was observed in the forestland, while cultivated land was with 1.1 g kg^{-1}.

Table 4.6 shows that forestland had the highest content of available P (8.78 mg kg^{-1}), Cultivated land had the least (5.47 mg kg^{-1}) and this could be attributed to crop uptake of phosphorus since it has been proven that legumes use up phosphorus more and the presence of legume facilitates the utilization of soil phosphorus by crops in the low P soil of Northern Guinea Savanna of Nigeria Thomas (2000).

Cation Exchange Capacity (CEC) decreased slightly under cultivation (8.54 cmol kg^{-1}), and increased slightly with forest 8.60 cmol kg^{-1} in CEC would imply that soil health/quality over the years had been positively impacted upon by the management practices (McRae and Mehuys, 1988; Carlson and Huss-Danell, 2003). Table 4.7 shows that lower slope had the least bulk density (1.37 Mg m^{-3}) while upper had the highest bulk density 1.47 (Mg m^{-3} then 1.44 (Mg m^{-3}) record in the middle slope, it's also shows that there was increase in organic carbon contents under middle slope 11.0 g kg^{-1} fallowed by upper slope with 9.30 g kg^{-1} then lower slope 7.40 g kg^{-1}. Total N content of 1.20 g kg^{-1} was observed at upper slope, 1.4 g kg^{-1} and 0.9 g kg^{-1} at middle and lower slope respectively.

Table 4.7 shows that upper slope had the highest content of available P among the other slopes, this could be attributed to crop uptake of phosphorus and the presence of legume facilitates the utilization of soil phosphorus by crops in the low P soil of Northern Guinea Savanna of Nigeria (Kalm *et al*. 2002). It shows that CEC decreased slightly under lower slope 7.97 cmol kg^{-1}, 8.46 cmol kg^{-1} at upper slope and increased under middle slope 9.28 cmol kg^{-1} . Table 4.7 shows that lower slope increased in dry mean weight diameter with 1.32mm while upper slope had 1.22 mm. Lower slopes show least in wet mean diameter (1.19 mm) and upper slope (1.21mm), middle slope shows increase with (1.28 mm) table 4.7. It shows that pH in water decreased slightly under middle slope and increased under lower slope. Decrease in soil pH however, was not sufficient to hamper crop growth. Both pH in H_2O and $CaCl_2$ did not followed the same trend. Management practices which were superior by improving soil quality were ascertained from results and a summary of the threshold limits using soils that were superior as a baseline is presented in Tables 4.8 and 4.9.

Table 4.6: Threshold limits for soil quality assessment in Afaka Alfisols Using Minimum Data Set

Soil parameter	**Forest**	**Cultivated land**
Bulk density (Mg m^{-3})	1.34	1.46
Organic carbon (g kg^{-1})	10.2	8.21
Total nitrogen (g kg^{-1})	1.2	1.1
Available phosphorus (mg kg^{-1})	8.78	5.47
CEC (cmol kg^{-1})	8.60	8.54
Dry mean weight	1.24	1.19
Wet mean weight	1.27	1.19
pH (H_2O (1:2.5)	7.16	6.90
pH ($CaCl_{2)}$ (0.01M)	6.49	6.22

Table 4.7: Threshold limits for soil quality assessment in Afaka Alfisols.

Properties	upper	middle	lower
Bulk density (Mg m^{-3})	1.47	1.44	1.37
Organic carbon (g kg^{-1})	9.30	11.0	7.40
Total nitrogen (g kg^{-1})	1.20	1.4	0.9
Available phosphorus (mg kg^{-1})	9.31	4.12	7.94
CEC (cmol kg^{-1})	8.46	9.28	7.97
Dry mean weight	1.22	1.11	1.32
Wet mean weight	1.21	1.28	1.19
pH (H_2O (1:2.5)	7.03	6.97	7.08
pH ($CaCl_{2)}$ (0.01M)	6.38	6.37	6.32

Table 4.8: Soil Quality Monitoring and Evaluation in Afaka forest, Nigeria

	Soil of Afaka	plantation	
Soil parameter	High	medium	low
Bulk density(Mg m^{-3})	≥ 1.4	1.2– 1.4	< 1.2
Organic carbon (g kg^{-1})	> 15	10 – 15	< 10
Total nitrogen (g kg^{-1})	0.3	0.2-0.3	<0.2
Available phosphorus(mg kg^{-1})	≥ 4.0	2.5 – 4.0	< 2.5
CEC(cmol kg^{-1})	>8.0	7.0 – 8.0	< 7.0
Dry mean weight	≥1.5	1.3 – 1.5	< 1.3
Wet mean weight	≥1.5	1.3 – 1.5	< 1.3
pH (H_2O(1:2.5)	>5.5	4.8 – 5.5	< 4.8
pH ($CaCl_{2)}$ (0.01M)	>4.5	4.0 – 4.5	< 4.0

Note: > is greater than, < less than, ≥ greater than or equal to, ≤ less than or equal to

4.4 Soil quality evaluation

Soil of the land uses and slopes were cumulatively rated for quality base on the SMAF protocol and the results are shown in Table 4.9. Each of the indicator values was divided by a common denominator (highest possible measurement for indicator in the land uses and slopes plus 10 % of it) before being subtracted from 1 (in the case of parameters for which less is better). There is the tendency for indicator with lower denominator to have higher value than indicator with higher denominators. These explain variability in the individual scores for different indicators. When cumulatively put together however, upper forest soil had the highest score index followed by cultivated lower slope soil, cultivated upper, middle forest, forest lower and cultivated lower slope land respectively. The variation order of soil (upper forest>lower cultivated>upper cultivated>middle forest>lower forest>middle cultivated) indicate the direction of good quality of soil.

Soil quality was assessed using a score scale of 1 to 6; where 1 is rated best and 6 rated worst. Thus; upper forest with highest total score was rated best, while middle cultivated with lowest total score rated worst. Upper forest scored best and enhance soil quality conditions (optimum soil organic carbon , total nitrogen , available phosphorus, potassium, EC, and bulk density), while middle slope cultivated lands were rated worst (low organic carbon, low k, moderate phosphorus, moderate nitrogen, low bulk density and electrical conductivity (Table 4.9)

4.5 Combining the indicators scores into the index

This involves developing scoring function for each individual soil quality indicator and transforming the score into dimensionless values thus ranking them into a specified numerical value (Anikwe 2006). Each individual indicator is combined with several other indicators in the minimum data set to form a set of soil quality indicator to evaluate a soil for specified applied practical purpose (Anikwe 2006). It is important to note that for each indicator, a scoring function and realistic baseline and threshold value. The values for the scoring function are either neither specific for a kind of land use for specific kind of sol quality evaluation for specific management practice (Anikwe 2006). Therefore soil quality rating is calculated by summation of weight scores for each of soil function.

Table 4.9: combining indicators the scores into the index (SMAF protocol)

Functions	Indicators	F upper	F middle	F lower	C upper	C middle	C lower
Ease of tillage	Bulk density	0.015	0.014	0.015	0.014	0.014	0.013
Biological activities	Organic matter	0.12	0.12	0.123	0.087	0.096	0.06
Support plant growth	Total N	0.014	0.014	0.009	0.011	0.014	0.009
Support plant growth	Available p	0.08	0.05	0.024	0.096	0.032	0.134
Plant nutrient	CEC	0.09	0.09	0.078	0.079	0.095	0.081
Resistance to air erosion	Dry mean weight	0.012	0.012	0.013	0.012	0.010	0.013
Resistance to water erosion	Wet mean weight	0.013	0.010	0.013	0.01	0.015	0.010
Salinity	pH (H_2O(1:2.5)	0.072	0.062	0.072	0.069	0.069	0.068
Salinity	pH ($CaCl_{2)}$ (0.01M)	0.065	0.063	0.066	0.061	0.061	0.063
	Total (Index)	0.481	0.435	0.413	0.439	0.406	0.451

Table 4.10: Ranking of soil quality under different land use and slopes

Slope positions	Total score	Percentage	Ranking
F upper	0.481	48.1	1
C lower	0.451	45.1	2
C upper	0.439	43.9	3
F middle	0.435	43.5	4
F lower	0.413	41.3	5
C middle	0.406	40.6	6

A score scale of 1 to 6 was used in the assessment of parameters; where 1 is best and 6 is the worst condition.

4.6 Correlation Analysis

Results showing simple linear correlation coefficient of selected soil chemical properties measured with each other, between land uses, topographic positions and slope aspects were presented in Table 4.11. The correlation coefficient values show highly significant relationships. Cation exchange capacity (CEC) show significantly and positively association with calcium (r=0.9302), electrical conductivity (r=0.6657) and magnesium (r=0.8461). Similarly, calcium shows strong positive correlation with electrical conductivity (r=0.6412), magnesium (r=0.7647), pH ($CaCl_2$) (r=0.6762) and pH (H_2O) (r=0.7665). Electrical conductivity correlated positively with magnesium (r=0.7068), organic carbon (r=0.5733) and total nitrogen (r=0.5925), implying that the surface soil layer was the most biologically active part of the profile. Magnesium exhibited positive correlation with organic carbon (r=0.5661) and total nitrogen (r=0.4588). Sodium correlated positively with organic carbon (r=0.6176) and total nitrogen (r=0.6278). Total nitrogen was strongly associated (r=0.5438) with total organic carbon and decreased consistently with increasing soil depth under all land use systems. Result of the present study agrees with findings of other workers (Malo *et al*., 2005; Heluf and Wakene, 2006) that the decrease in total nitrogen with increasing depth was due to declining humus with depth. The pH ($CaCl_2$) positively associate with pH (r=0.8934); Total porosity was significantly negatively correlated with available moisture content at 0-10 cm (r=-0.4798). This revealed that increase in porosity could result to a decrease in moisture retention. Similarly, clay shows strong positive correlation with dry mean weight diameter (r=0.4635), silt (r=0.7922) and negative correlation with sand (r=-0.6904); thus implied that finer particles influence micro-pores than total porosity, hence increased retention of moisture. Silt/clay ratio exhibited negative correlation with silt (r=-0.5262), perhaps, due to high degree of weathering potentials as soils in the study area were relatively young. Silt correlated negatively with silt/clay ratio (r=-0.9345) to suggest that higher silt content may lower binding influence due to clay and therefore greater susceptibility to erosion. The decrease in silt/clay ratio with depth and variation in other physical properties; such as bulk density, porosity, water retention potential in all the two sites agree with an earlier study by Lal (2001) that physical properties for majority of tropical soils change due to soil management, which may range widely from soil to soil even within the same toposequence. However, it was noticed that silt/clay ratios were high for soils in Afaka. This might be attributed to transportation of silt and clay particles down the slope by erosion.

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Table 4.11: Linear correlation coefficient of soil properties measured with each other, between land uses, topographic positions and slope.

	CEC	TP	Awc1	Ca	Ec	Mg	Na	Oc	TN	$CaCl_2$	K	S/C	SOC
CEC													
TP	-0.0106												
Awc1	0.0263	-0.4533											
Ca	0.9302**	-0.4798*	0.7514**										
Ec	0.6657**	-0.3160	0.0807	0.6412**									
Mg	0.8461**	-0.3406	0.2449	0.7647**	0.7068**								
Na	0.3689	-0.0109	-0.1415	0.2535	0.352	0.3412							
Oc	0.1925	-0.1193	-0.0518	0.0321	0.5733*	0.5661*	0.6176**						
TN	0.0178	0.3588	0.2250	-0.1297	0.5925**	0.4588*	0.6278**	0.5438*					
CaCl	0.0432	0.2180	-0.0287	0.6762**	0.3158	0.2929	0.3719	0.0711	0.1134				
K	0.431	0.3071	-0.0343	0.1323	-0.0145	0.1795	0.3289	0.0632	0.0942	0.0749			
pH	0.1095	0.1204	-0.2327	0.7665**	0.1423	0.0584	0.1786	-0.1529	0.0874	0.8934**	-0.5262**		
SOC	0.0933	0.1204	-0.2327	0.3961	0.01	0.391	0.0405	-0.1993	-0.1954	-0.1343	-0.3993	-0.9345**	

*Significant at $P \leq 0.05$, ** = highly Significant at $P \leq 0.01$, AP = Available phosphorus, BD = Bulk density, CEC = Cation exchange capacity, EC = Electrical conductivity, OM = Organic matter, TN = Total nitrogen, TP = Total porosity. Mg = magnesium, Na = sodium, K = potassium, SOC = carbon stock, S/C = silt

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary

The study was conducted with the aim to determine effect of land use on selected physical and chemical properties of Alfisols in Guinea savanna and to suggest management practices that would sustain croplands for sustainable productivity conserve the environment and assess quantitatively, effect of forest and cultivation land uses on soil carbon stock. Rigid grid detailed survey plan was employed. Undisturbed core soil samples from depth of 0- 5 cm (top soil) and 5-10 cm (lower layer) were collected at auger points determined along traverses from cultivated land and in adjacent forest, in each delineated geomorphic position of the study area for water retention potential, bulk density and hydraulic conductivity determinations. Other soil samples collected were used for wet and dry aggregate stability determinations and selected chemical properties. The sampled area covered 1 km by 1 km dimension and the different locations were selected based on identified typical Afaka forest vegetation, typic-toposequence and crop cultivated sites. Data collected was analyzed with SAS software (SAS, 1997) computer package to test for significant difference among treatments. In conditions where there was significant difference, mean comparison was performed with least significant different (LSD). The results indicate that textural class of all soils under the land use types on three topographic positions was sandy loam. The results also show no significant difference in these land use types and slope positions ($p<0.05$) on percentage sand, silt, clay and silt/clay ratio, soil aggregate fractionate, soil bulk density, soil pH in water and $CaCl_2$, and dry and wet aggregate stability. However, saturated hydraulic conductivity and dry and wet aggregate stability were statistically not affected by these treatments ($p<0.05$). The results also show that soil moisture content was significantly affected ($p<0.05$) by land use type and slope and soil carbon stock show significant difference in land use type. The results also show no significant difference between these land use types and slope positions ($p<0.05$) on cation exchange capacity, total nitrogen, available phosphorus, sodium, calcium, potassium and aluminum. Magnesium shows significant difference on slope position in cultivated land. Soil quality evaluation was based on the soil management assessment framework (SMAF) suggested by Andrews *et al*. (2004), scoring functions for 14 potential soil quality indicators (Wienhold *et al*., 2009) and a minimum data set (MDS) was established. The MDS selected in this study include soil functions such as ease of tillage, salinity support for plant growth, bulk density (BD), CEC, total N, available P, and exchangeable K were used as indicators for plant growth support, while organic carbon was indicator for biological activity in the soil, MWD was used to assess erodibility of the soils. Alfisol at the upper forest land had better soil quality than those at the slope positions. Slight change in CEC would imply that soil health/quality over the years had been positively impacted upon by the management practices.

5.2. Conclusion

From the study, it was concluded that soil physico-chemical properties significantly varied among land use systems and slope positions in the study site. Shift in land use systems from natural forest to agricultural land use systems had detrimental effect on soil physical and chemical properties. The result indicates that organic matter concentration declined particularly in the upper slope of cultivated land, when compared to forest land. The result also indicates impact of forest on compaction of soils by the relatively high bulk density values recorded in soils under cultivated land use type on almost all the topographic positions.

However, slope position affected most selected soil properties under different land use types considered in this study. The study indicates that cultivation led to increased bulk density, porosity and sodium content, reduced organic carbon, aggregate stability and water retention, total nitrogen, available phosphorus and potassium compared to forest land. The soil quality management should address the problem of land degradation which will help in mitigating the effects of climate change and global warming.

Due to population pressure, large tracts of Afaka forest land had been converted to cultivated lands and some are put under artificial plantations dominated by E*ucalyptus rudis, Cassia siamea*, *Eucalyptus crebra*, *Khaya senegalensis*, C*assia siamea and Albizzia lebbek*, *Anogeisus leiocarpus*, *Eucalyptus camdulensis and Callitris robusta.* Forest soils have excellent potentials for sequestering organic carbon and maintaining or improving soil quality indicators; such as, bulk density, aggregate stability, soil moisture content, soil organic carbon content and soil structure. Lower soil bulk density and pH levels, higher level of soil aggregation and lower susceptibility to wind and water erosion were observed on the cultivated land.

5.3 Recommendations

It is recommended that integrated land management should be practiced such as practical soil conservation policies and measures to ensure sustainable use of soil as a resource to combat the ongoing soil changes and improve soil fertility in different land use systems to overcome land degradation and achieve sustainable agricultural production in the study area.

Further studies involving longer term research and evaluation of land uses for carbon sequestration in soil aggregate fraction potentials, as well as socio-economics of the system is suggested. This would allow for better discernment of soil quality changes and cost benefits of the system.

Long-term experiments (10–30 years) should be conducted to establish the positive and negative effects of different land uses on soil indicators for developing models so that appropriate action could be taken accordingly

REFERENCE

.

Abawi, G.S. and Widmer T.L. (2000) Impact of soil health management practices on soil borne pathogens, nematodes and root diseases of vegetables crops. *Applied Soil Ecology,* 15: 37–47.

Abayneh, E. (2001). Some physicochemical characteristics of the Raya valley soils. *Ethiopia Journal of Natural Resources*, 3(2): 179-193.

Adeboye M. K. A, Osunde A. O., Ezenwa, M. I. S., Odofin, A. J. and Bala, A. (2009). Evaluation of the fertility status and suitability of some soils for arable cropping in the southern Guinea savanna of Nigeria. *Nigerian Journal of Soil Science*, 19 (2): 115-120.

Adeoye, K. B., and Mohamed-Saleem, M. A. (1990). Comparison of effects of tillage methods on soil physical properties and yield of maize and stylo in a degraded ferruginous tropical soil. *Soil and Tillage Research,* 18: 63-72

Agbenin, J.O. (1995). Laboratory manual for soil and plant analysis (selected methods and data analysis).

Aggregate and Particle Associated Organic Carbon under Different Land Uses in Nepal. *Soil Science Society of America Journal*, 71(4): 94-1203.

Agoume, V. and Birang, A.M. (2009). Impact of Land-use Systems on some Physical and Chemical Soil Properties of an Oxisol in the Humid Forest Zone of Southern Cameroon. *Agriculture, Ecosystems, and Environment,* 87: 119-120.

Ahmad, W. and Khan, F. (2009). Managing soil fertility for sustained crop productivity on eroded lands of District Swabi. Ph.D. Thesis, Department of Soil and Environmental Sciences, Agricultural University, Peshawar. 161-169.

Ahmed, H., (2002). Assessment of spatial variability of some physicochemical properties of soils under different elevations and land use systems in the western slopes of Mount Chilalo, Arsi. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia. 111

Ahmed, F. and Tan. (1986). Effect of lime and organic matter on soya bean seedlings grown in Al toxic soils. *Soil Science Society of American Journal,* 50: 656-661.

Ahmed, H., Magid, G.E., Schuman and Hart, R.H. (1987). Soil and vegetation responses to simulated trampling. *Journal of Range Management,* 4:303-306.

Ahn, P. M. (1993). Tropical soils and Fertilizer use. Intermediate tropical agriculture serious. Malaysia: Long man Group UK Limited *America Journal,* 68: 1945-1962.

Alemayehu, T., (1990). Soil and irrigation management in the state farms. pp. 47-52. In *Proceeding of the first Natural Resource Conservation Conference.* Natural Resource Degradation, a Challenge to Ethiopia, 7-8 February 1989. Addis Ababa, Ethiopia. Institute of Agricultural research (IAR).

Amezketa, E. (1999). Soil aggregate stability: A review *Journal of Sustainable Agriculture,* 14:83-151

Anderson, J.M. and Ingram, J.S.I. (1993). Tropical Soil Biology and Fertility: A Handbook of Methods (2nd ed.). C.A.B. International Wallingford, U.K. page 221**.**

Andrews S. S., Karlen, D. L. and Cambardella, C. A. (2004) The soil management assessment framework: A quantitative soil quality evaluation method. *Soil Science Society American Journal*, 68: 1945-1962.

Andrews, S. S. and Carrol C. R. (2001). Designing a decision tool for sustainable agroecosystem management: Soil quality assessment of a poultry litter management case study. *Ecological. Application,* 11 (6): 1573-1585.

Andrews, S.S., Karlen D.L. and Cambardella C.A. (2004). The soil management assessment framework: A quantitative soil quality evaluation method. *Soil Science Society of Nigeria,* 11 (6): 1573-1585

Angers, D. A., Edwards, L. M., Sanderson J. B. and Bissonatte, N. (1999). Soil organic matter quality and aggregate stability under eight potato cropping sequence in a find sandy loam of prince Edward island. *Canadian Journal of Soil Science,* 79:411-417.

Anikwe, M.A.N, Obi M. E, and Agbenin, N.N. (2003), Effect of crop and soil management practices soil compatibility in maize and groundnut plots in a Paleustult in southeastern Nigeria. *Plant and Soils*, 253:457-465

Anikwe, M.A.N. (2006) soil quality assessment and monitoring: A review of current research effort.

Arshad, M.A. and Martin, S. (2002). Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems and Environment,* 88: 153–160.

Ayoubi, S., Khormali, F., Sahrawat, K. L. and Rodrigues de Lima, A. C. (2011). Assessing the Impacts of Land Use, 87: 152–160

Barauah, T.C. and Barthakulh, H.P. (1997). *A textbook of Soil Analysis*. New Delhi, India: Viskas Publishing House. 334.

Baror, Y. and Danin A. (1986). Mechanism of cyanobacterial crust formations and soil stabilization in the north western negev. *Israel Society of Microbiology,* 13; 55-64.

Bationo, A. and Mokwunye, A.U. (1991). Alleviating soil fertility constraints to increased crop production in West Africa: the experience in the Sahel. p195-215. In: A.U. Mokwunye (ed.) Alleviating soil fertility constraints to increased crop production in West Africa. Kluwer Academic Publishers, Netherlands.

Bationo, A., Mokwunye, P.L.G., Vlek, S. and Shapiro, B.I. (2003). Soil fertility management for sustainable land use in the West Africa Sudano- Sahelian zone. In soil fertility management in Africa: A regional perspective (Gichuru, A. Bationo, M.A., Bekunda, H.C., Goma, P.L., Mafongoya, D.N.. Mugendi, H.M., Murwira, S.M., Nandwa, P., Nyathi & M.J. Swift, eds.), p255-292. Tropical Soil Biology and Fertility Institute of CIAT; Nairobi, Kenya.

Batjes, N. H. (2002). Carbon and nitrogen stocks in the soils of Central and Eastern Europe. *Soil Land Use and Management,* 18:324-329.

Barauah, T. C. and Barthakulh, H. P. (1997). A textbook of soil analysis. Vikas Publishing House, New Delhi India

Belay, S. (2003). Integrated watershed management approach to sustainable land management (Experience of SARDP in East Gojjam and South Wollo). pp.127-136.*In*: Tilahun Amede (ed.), *Proceedings of the Conference on the Natural Resource Degradation and Environmental Concerns in the Amhara National Regional State:* Impact of Food Security, July 24-26, 2002, Bahir Dar. Addis Ababa, Ethiopia. The *Ethiopian Society of Soil Science* (ESSS).

Belay T., (1996). Characteristics and landscape relation hip of Vertisols and Vertic Luvisol of Melbe, Tigray, Ethiopia. SINET: *Ethiopian Journal of Soil Science*, 19 (2): 93-1113.

Bell, M.J., Bridze, B.J. Harch, G.R. and Orange, D.N. (1997). Physical rehabilitation of degraded krasnozems using ley pasture. *Australian Journal of Soil Resource,* 35:1093-1113.

Bennie, A.T. and Krynauw, G.N. (1985). Causes, adverse effect and control of soil compaction. *South. African Journal of Plant and Soil,* 3: 109-112.

Bhaskar, B.P, Butte P. S. and Brauah, U. S. (2005). Characterization of soils in the ‘Bil’ environments of Brahmaputra valley in Jorhat district, Assam for land use interpretation. *Journal of Indian Society of Soil Science,* 53**:** 3-10

Binkley, D. and Sollins, P. (1990). Factors determining differences in soil pH in adjacent conifer and alder-conifer stands. *Soil Science Society of America Journal,* 54: 1427-1433.

Binkley, D., Dunkin, K.A. Debell, D. and Ryan, M.G. (1992). Production and nutrient cycling in mixed plantation of Eucalyptus and Albizia in Hawaii. *Forest Science,* 38: 393-408. 53

Birkeland, P, W. (1984). *Soils and Geomorphology*. Oxford University Press, New york..

Blake,G. R. and Hartge, K. H. (1986) Bulk density ,p 363-376 in A Klute (ed) *Method of Soil Analysis*, part 1 second edtion .As A monograph No 9 Madison, WI

Blanco-Canqui, H. and Lal, R. (2004). Mechanism of carbon sequestration in soil aggregates. *Criteria Review Plant science*, 23:481-504.

Bohn, H.L, McNeal, B.L. and. O'Connor, G.A (2001). *Soil Chemistry, 3rd Edition*. New York, USA: John Wiley and Sons, Inc. 307.

Boix-Fayos, C., Calvo-Cases, A., Imeson, A.C. (2001). Influence of soil properties on the aggregation of some Mediterranean soils and the use of aggregate size and stability as land degradation indices, 44; 47- 67.

Bone, F., Rubio, R. and Morales, A. (2008). ArbscularMycorrhizal fungi and soil aggregation nutrition vegetation. *Journal of Soil and Plant Nutrition*, 8 (2): 9-18.

Bossuyt, B., J. Diels and J. Deckers, (1999). Changes following cultivation and reforestation of looss soils in central Belgium: *Consequences for Future Land use*, 3: 151-166.

Bouyoucos, G.J. (1962). Hydrometer method improvement for making particle size analysis of soils. *Agronomy Journal*, 54: 179-186.

Brady N.C. and Weil, R.. (2002). The Nature and Properties of Soils. 13th edition. Singapore, Pearson Education. 976pp.

Brady, N.C. and Weil, R.R. (1999). The nature and properties of soil.12th edition. Prentice Hall, New Jersey, USA.881

Brady, N.C. and Weil, R.R. (2002). *The Nature and Properties Of Soils, 13th Edition.* New Jersey, USA: Prentice- Hall Inc. 960.

Brar, G.S. and Unger, P.W. (1994). Soil temperature simulation with varying residue management. *Journal of Agronomy and Crop Science*, 172: 1-8.

Bray, K.H. and Kurtz, L.T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Science Society of American Journal*, 59: 39-45.

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen total. P.595-642. in A.L. Page et al. (ed.) *Methods of Soil Analysis*, Part 2. Chemical and microbiological properties. SSSA, Madison, Wisconsin.

Briggs, J.D. and Courtney, F.M. (1989). Agriculture and environment. The Physical Geography of Temperate Agricultural systems. Longman Group UK Limited. Singapore. BSI, 1975. Methods of testing soils for civil engineering purpose. British standards 1377. British standards institution, Landon.

Bronick, C.J., and R. Lal. (2005). Soil structure and management: a review. *Geoderma*, 124(1/2): 3–22.

Brubaker, S. C., Holzhey, S. C. and Brasher, B. R. (1992). Estimating the clay content of soils. *Science Society of American Journal*, 56: 1227-1232.

Bruun, H.H., Fritzboger, B. Rindel P.O. and Hansen, L. (2001). Plant species richness in grasslands: The relative importance of contemporary environment and land-use history since the Iron Age. *Ecography*, 24: 569-578.

Buol, S.W., Hole F.D. and McCracken, R.J. (1997). *Soil Genesis Classification*. The Iowa State University Press, Ammes.360.

Buol, S.W., Hole, F.D. and McCracken, R.J. (1989). *Soil Genesis and Classification, 3rd Edition. Ames, IA*: New Delhi, India: The Iowa State University Press. 446.

Cadisch, G. and Giller, K.E. (1997). Driven by Nature, Plant Litter Quality and Decomposition. CAB International, Wallingford

Cambardella, C.A., Gajda, A.M., Doran, J.W., Wienhold, B.J. and Kettler, T.A. (2001). Estimation of particulate and total organic matter by weight loss-ignition. In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (eds). *Assessment methods for soil carbon*, pp. 349-359.

Campbell, C.A., McConkey, B.G. Zentner, R.P. Sells F .and Curtin, D. (1996). Long-term effects of tillage and crop rotations on soil organic carbon and total nitrogen in a clay soil in south western Saskatchewan. *Canadian Journal of Soil Science,* 76: 395-340.

Campbell, C.A. and Souster W., (1982). Loss of organic matter and potentially mineralizable nitrogen from Saskatchewan soils due to cropping. *Canadian Journal of Soil Science* 62:651-656.

Capriel, P., Beck T., Borchert H., and Harter P. (1990). Relationship between soil aliphatic fraction extracted with supercritical hexane, soil microbial biomass and soil aggregate stability. *Soil Science Society of American Journal,* 54:415-420.

Caravaca, F., Hernandez, T. Garcia, and Roldan, A. (2002). Improvement of rhizosphere aggregate stability of afforested semi-arid plant species subjected to mycorrhizal inoculation and compost addition. *Geoderma*, 108:133-144.

Carlson, G., and Huss-Danell, K. (2003). Nitrogen fixation in perennial forage legumes in the field. *Plant and Soil*, 253: 353- 372.

Caron, J., Kay B. D. and Stone J. A. (1992). Improvement of structural stability of a clay loam with drying. *Soil Science Society of American Journal,* 56:1587-1590.

Carter, M. R. (1993). Soil sampling and methods of analysis. *Canadian Society of Soil Science*, 62:651-656

Çelik, I. (2005). Land use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. *Soil and Tillage Research*, *83*: 270-277.

Chan, K. Y. and Heenan, D. P. (1996).The influence of crop rotation on soil structure and physical properties under conventional tillage. *Soil and Tillage Research,* 37:113-125.

Chang, K. Y. and Heenan, D. P (1999). Lime induce loss of soil organic carbon and effect on aggregate stability. *Soil Science Society of American Journal,* 63:1841-1844.

Chang, S. C., West .T, and Radcliff, D E.(1994). Morphological properties of surface seals in Georgia soils. *Soil Science Society of American Journal, 58:901-910*.

Chapman, H.D. (1965). Total exchangeable bases. In: Black, C.A. (ed.). Methods of soil analyses, part II. *American Society of Agronomy*, 56: 902-904.

Colazo, J.C., Buschiazzo, D.E. (2010). Soil dry aggregate stability and wind erodible fraction in a semi-arid environment of Argentina. *Geoderma.* 159; 228-236.

Colchin, A. Clack., P., Oades, J. M. and Skjemstaccl, J. O. (1985). The effect of cultivation on the composition of organic matter and structural stability of soils. *Australian Journal of Soil Research, 33: 975-883.*

Colombo C. and Terrent J (1991). Relationship between aggregation and iron oxide in Terra Rossa soil from southern Italy *catena*, 18:51-60 component of soil quality. *Applied Soil Ecology*, **15: 3–11**.

Cooter, D. R., Malcolm –McGovern, C. A., Wall G. J., Dickison W. T., and Rudrarp (1988). Seasonal variation of irrigation based on shear strength and aggregate stability in some Ontario soils. *Canadian Journal of Soil Science.*68:405-416.

CSIRO, (1988). CSIRO disc permeameter instruction manual.CSIRO Center for Environmental Mathematics, Canberra, Australia.

Curtin, D, Cambel, C. A., Zenter, R. P. and Land ford, G. P. (1994). longtime management and clay dipersility in two haploboroll in Saskshwen. *Soil Science Society of American Journal, 58:962-967.*

Curtis, P.E. and Courson, R.L. (1981). *Outline of soil fertility and fertilizers, 2nd Edition*. Champaign: Stipes Publishing Company. 250.

Denef, K. and Six J (2003). Clay mineralogy modifies macro aggregate stabilization through active root growth, plant residues and associated microbial activity *European Journal of Soil Science*, 33:1599-1611

Denef, K., Six, J., Bossuyt, H., Frey, S, D., Elliot, E. T., Merckx, R. and Paustain ,K (2001). Influence of dry –wet cycles on the interrelationship between aggregate, particle organic matter, and microbial community dynamics. *Biology and Biochemistry of Soils*, 33:1599-1611

Dengen, B. P. (1997). Macro aggregation of soil by biological bonding and binding mechanism and the factors affecting these: A review *Australian Journal of Soil Research,* 35:431-459

Dengen, B. P., Sparling, G. P. (1996). Changes in aggregation do not correspond with change in labile organic C fraction in soil amended with 14C-glucose *Biology and Biochemistry of Soils,* 28:453-462.

Dengen, B. P., Sparling G. P. and Abott, L. K. (1994). The contribution of hyphea, roots and organic C constituent to the aggregation of a sandy loam under long term clover – based or grass pasture. *European Journal of Soil Science,* 45: 459-68

Dexter, A. R. (1988). Advance in characterization of soil structure. *Soil and Tillage Research,* 11:199-238.

Diak, M. and Scott, D. E (2001). Development of soil quality index for the Chalmers silty clay loam from the Midwest USA . Agricultural research service. *National Soil Erosion Research Laboratory*, West Lafayette, n 47907-1196pp

Dixon, R. K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C., and Wisniewski, J. (1994). Carbon Pools and Fluxes of *Global Forest Ecosystems for Science* 263: 185–190.

Doran, J. W., and Parkin, T. B. (1994). Defining and assessing soil quality. Pages 3-21 in J. W. Doran et al., (eds.) Defining soil quality for a sustainable environment. *Soil Science Society of America* Special Publication no. 35, Madison, Wisconsin.

Doran, J.W. and Safely, M. (1997). Defining and assessing soil health and sustainable productivity. In:Pankhrust, C. *et al.* (Ed.). *Biological Indicators of Soil Health*. Wallingford, UK: CAB International. PP. 1-28.

Doran, J.W. and Parkin, T.B., (1994). Defining and Assessing Soil Quality. In: Defining Soil Quality for a Sustainable Environment, 59 – 74.

Doran, J. W., Varvel, G. E. and Culley, J. B. L., (1994) Tillage and Residue management effect of Soil quality on sustainable land management. In Wood R.C., Dumanski, *Journal for Sustainable Land Management* for the 21st Century vol. 2 plenary Papers University of Lethbridge, Canada. 59 – 74.

.Doran, J.W., Jones, A.J. (1996). Methods for Assessing Soil Quality. *Soil Science Society of America,* Special Publication, 49.

Doran, J.W., Parkin, T.B., (1994). Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. Soil Science Society of America Special Publication, vol. 35. *Soil Science Society of America,* Madison, Wisconsin, pp. 3–21.

Doran, J.W., Zeiss, M. R., (2000). Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology,* 15; 3–11.

Doran, J.W. (2002). Soil health and global sustainability: translating science into practice. *Agriculture, Ecosystem and Environment,* 88: 119–127.

Dudal, R. and Decaers, J. (1993). Soil organic matter in relation to soil productivity. pp. 377-380. In: Mulongoy J. and R. Marcks (Eds.). Soil Organic Matter Dynamics and

Sustainability of Tropical Agriculture. *Proceeding of International Symposium Organized by the Laboratory of Soil Fertility and Soil Biology*, Ktholeke University Leuven (K.U. Leuven) and the International Institute of Tropical Agriculture (IITA) and Held in Leuven, Belgium, 4-6 November 1991. John Wiley and Sons Ltd., UK.

Edwards, A.D. and Bremner, J.M. (1967). Microaggregates in soil. *Journal of Soil Science*. 18:64-73

Ellert, B. and Gregorich, E G (1996). Storage of C N and P in cultivated and adjacent forest soil of Ontario. *Soil Science,* 19:587-603.

Elliort, E. T. (1984). Aggregate structure and carbon nitrogen and phosphorus in native and cultivated soils. *Soil Science Society American Journal*, 50:627-633.

Elliot E. T. and Camberdella, C A (1991). Physical separation of soil organic matter. *Agricultural Ecosystem and Environment*.34; 407-419

Elliot, E.T.. Anderson R.V. Coleman D.C., and Cole. C.V. (1980). Habitable pore space and microbial trophic interactions. Oikos 35:327-335

Elliot, W.J. (2003). "Soil Erosion in Forest Ecosystems and Carbon Dynamics", in Kimble, J.M.; Heath, L.S.; Birdsey, R.A. and Lal, R. (Eds.), *The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect*. CRC Press, Boca Raton, FL.175–190. 54 *European Journal of Agronomy,* 20: 71–87.

Enwezor, W.O., Udo E.J., Usoroh, N.J., Ayotade, K.A., Adepetu, J.A., Chude V.O. and Udegbe, C.I. (1989). Fertilizer Use and Management Practices for Crops in Nigeira (series No. 2). Fertilizer Procurement and Distribution Division, FederalMinistry of agriculture, *Water Resources and Rural Development, Lagos, Nigeria*. p163.

Esu, I. E. (1989). Pedological characterization of the soil of the Hadejiya alluvial complex in the semi arid region of Nigeria. 179 – 190.

Esu, I. E. (1991). Detailed soil survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. 72 pp.

Evrendilek, F., Celik, I., and Kilic, C. (2004). Changes in soil organic carbon and other physical soil properties along adjacent Mediterranean forest, grassland, and cropland ecosystems in Turkey. *Journal of Arid Environment, 59*: 743-752.

Eylachew Z. (1999). Selected physical, chemical and mineralogical characteristics of major soils occurring in Chercher highlands, eastern Ethiopia. *Ethiopian Journal of Natural Resource,* (2): 173-185.

Eylachew Z., (2001). Study on physical, chemical and mineralogical characteristics of some Vertisols of Ethiopia. pp. 87-102. Wondimagne Chekol and Engda Mersha (Eds.). *In*: *Proceeding of the 5th Conference of the Ethiopian Society of Soil Science (ESSS),* March 30- 31, 2000. Addis Ababa, Ethiopia: The *Ethiopian Society of Soil Science* (ESSS).

Ezenwa, M. I. S. (1987). Some physicochemical characteristics of soil of basement complex adjoining basaltic rocks of northern part of Nigeria in the proceeding of the 15th annual conference of *Soil Science Society of Nigeria,* 205 – 214.

Federal Department Of Forestry Resources FDFR Afaka (1964)

Feller C., Balesdent J, Nicolardot B and Cerri C. (2001). Approaching functional soil organic matter pools through particle-size fractionation Examples for tropical soils. In Lal R, Kimble KM & Follet RF (eds) Assessment methods for soil carbon. *Advances in Soil Science,* 53-67

FFD., (2012). Fertilizer use and management practices for Nigeria. Federal Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria,:1-215.

Fisseha, H. (2014). Study of phosphorus adsorption and its relationship with soil properties, analyzed with Langmuir and Freundlich models. *Agriculture, Forestry and Fisheries,* 3(1): 40-51.

Food and Agriculture Organization (FAO), (1976). A frame work for land evaluation .Compiled and edited by: Keya Choudhury and Louisa, M., Jassen, J. 1998. *Terminology for integrated resource planning and management,* 69.

Food and Agriculture Organization (FAO), (1995). Programme for the world census of agriculture 2000. FAO statistical development series No.5, FAO, Rome.

Food and Agriculture Organization (FAO), (1997). African land covers classification, Rome
.

Food and Agriculture Organization (FAO). (2006b). Plant Nutrition for Food Security: A guide for Integrated Nutrient Management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome, Italy

Foster, D., Swanson, F., Abler, J., Burke, I. Brokaw, N., Tillman D. and Knapp, A. (2003). The importance of land-use legacies to ecology and conservation. *Bioscience, 53: 77-88.*

Foth, H.D. (1990). *Fundamentals of Soil Science, 8th Edition*. New York USA: John Wiley and Sons, Inc. 360.

Foth, H.D. and Ellis. B.G. (1997). *Soil Fertility, 2nd Edition.* LLC., USA: Lewis CRC Press 290.

Franzluebber, A. J. (2002). Soil organic matter stratification ratio as an indicator of soil quality. *Soil and Tillage Research,* 66: 95 -106.

Fuhrer,E.(2000).forest function ecosystem stability and management. *Forest Ecology and Management*, 132:29-38.

Fuller L. G., Gobi, T. B.and Oscarsan, D W (1995). Cultivation effect on dispersible clay of soil aggregates. *Canadian Journal of Soil Science .75:101-107.*

Gao, G. and Change, C. (1996). Change in cation exchange capacity and particle size distribution of soil associated with long term annual application of cattle feed lot manure. *Soil Science Society of Nigeria,* 161: 115-120.

Gee, G W and Bauder, J. W. (1986) particle size analysis .In method of soil analysis .I (ed. A.Klute) *American Society of Agronomy,* Madison .W.I.9,91-100.

Garcia, A., Rodriguez, B., Garcia, B., Gaborcik, N., Krajcovic, V. and Zimkova, M. (1990). Mineral nutrients in pasture herbage of central western Spain. Soil, grassland and animal relationship. Proceedings of 13th general meeting of the European Grassland. Banska Bystrica. Czechoslovakia. June 25-29, 1990.

Gee, G.W. and Or, D. (2002). Particle-size analysis. Pp 255-293. Inc: 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.M

Gee. G.W..and J.W. Bauder. (1986). Particle-size analysis. p. 383-411. *In* A. Klute (ed.) Methods of soil analysis. Part I. 2nd ed. *Agronomy,* 9:383-411

Geissen, V., Guzman, G. M. (2006). Fertility of tropical soils under different land use systems-a case study of soils in Tabasco, Mexico. *Applied Soil Ecology, 31*; 169-178.

Giller, K. E. and Cadisch, G. (1997). Driven by nature: a sense of arrival or departure. In: Cadisch, G. and Giller, K. E. Driven by nature: Plant Litter Quality and Decomposition. CAB International, Wallingford, UK pp 393-399

Gochin, A. and Asgan. H. (2008). Land use effect on soil quality indicators in North Eastern Iran *.Australian Journal of Soil Research, 46:27-36*

Gold, (2009). Effects of Land Use C(hange on Soil Properties and Organic Carbon at Dagdami River Catchment in Turkey. *Journal of Environmental Biology*30 (5); 825-830

Goldberg, S., Suarez, D. L. and Glaubing R. A. (1988).Factor affecting clay dispersion and aggregate stability of arid soils. *Soil Science,* 146:317-325

Gomez, A.A., Swete, D.E., Kelly, K.K. and Coughlan, K.J. (1996). Measuring sustainability of agricultural systems at the farm level. p401-409. *In*: Methods for Assessing Soil Quality, J.W. Doran and A.J. Jones (Eds); Special publication no. 49, *Soil Science Society of America*, Madison, USA.

Gong, J. L., Chen, N. F., Huang, Y, Huang, Z., and Peng, H. (2005). Effect of land use on soil nutrients in the Loess Hilly Area of the Loess Plateau, China. *Land Degradation and Development*, *17*(5): 453-465.

Granatstein, D., Bezdicek, D.F., (1992). The need for a soil quality index: local and regional perspectives. *American Journal Alternative Agriculture*. 7: 12–16.

Grant, C. D. Dexter, A. R. and Oades, J. M. (1992). Residual effect of addition of calcium compound on soil structure and strength. *Soil and Tillage Research*, 22:283-297.

Greenland, D.J. (1981). Soil management and soil degradation. *Journal of Soil Science*, **32**:301- 322.

Gregorich, E.G., C.M. Monreal, M.R. Carter, D.A. Angers and B.H. Ellert (1994). Towards a minimum data set to assess soil organic matter quality in agricultural soils, 75; 161-164.

Gregorich, E.G., Ellert, B.H., and Monreal, C.M. (1995). Turnover of soil organic matter and storage of corn residue carbon estimated from natural 13C abundance. *Canadian Journal of Soil Science*, 75: 161-164.

Gupta, P.K. (2000). Handbook of soil fertilizer and manure. New Delhi, India: Annis Offset Press. 39-70.

Gupta, V.V.S.R., and Germida, J..J. (1988). Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. *Soil Biology and Biochem*istry, 20: 777-786.

Halett, P. D and Young, I. M. (1999). Changes to water repellence of soil aggregate caused by substrate –induced microbial activity. *European Journal of Soil Science* 50:35-40.

Hamblin A. P. (1985). The influence of soil structure on water movement, crop root growth, and water uptake. *Advances in Agronomy* 38: 95-157.

Hao, X. and Chang, C. (2003). Does long-term heavy cattle manure application increase salinity of a clay loam soil in semi-arid Southern Alberta *Agriculture Ecosystem and Environment* 94(1): 89-103.

Harris, R..F. and Bezdicek, D.F. (1994). Descriptive aspect of soil quality/health. In: Doran, J.W.; Coleman, D.C. and Stewart, B.A. Defining soil quality for sustainable environment, p23-35, *Soil Science Society of America* special publication No 35. Madison. WI.

Hartemink, E.A. (1998). Soil chemical and physical properties as indicator of sustainable land management under sugar cane in Papua New Guinea. *Geoderma, 85*: 283-306.

Havlin, J.L., Beaton, J.D., Tsidale, S.L. and Nelson, W.L. 1997. *Soil Fertility and Fertilizer: Introduction to Nutrient Management, 6th Edition*, Preason education.633.

Havlin, J. L., Beaton, J. D., Tisdale, S. L. and Nilson, W. L. (1999). *Soil fertility and fertilizers: an introduction to nutrient management*, (6th ed.). Prentice Hall. Upper Saddle River, New Jersey

Haynes, R. J. (2000), Interactions between soil organic matter status, cropping history method of quantification and sample pretreatment and their effect on measured aggregate stability. *Biology and Fertility of Soil* 30 (4):270-275.

Haynes, R. J. and G.S. Francis (1993). Change in microbial C, soil carbohydrate composition and aggregate stability induced by selected crop and forage species under field condition. *Journal of Soil Science*, 44:665-675.

Haynes, R. J. and Swift, R. S. (1990). Stability of soil aggregate in relation to organic constituent and soil water content. *Soil Science*, 41: 73-83.

Hazelton, P. and Murphy, B. (2007). *Interpreting Soil Test Results: 2nd Edition.* CSIRO Publishing. 152.

Hedlund, A., E. and Witter B.X. (2003). Assessment of N, P and K management by nutrient balances and flows on peri-urban smallholder farms in southern Vietnam.

Heluf, G. and Wakene, N. (2006). Impact of land use and management practices on chemical properties of some soils of Bako area, western Ethiopia. *Ethiopian Journal of Natural Resources.* 8(2): 177-197.

Hendershot, W.H., Courchesne, F. and Schemenauer, R.S. (1992). Soil acidification along a topographic gradient on roundtop Mountain, Quebec, Canada. *Water, Air, and Soil Pollution*, 61(3-4): 235-242.

Herrick, J. E. and Jones, T. L. (2002). A dynamic cone penetrometer for measuring soil penetration resistance. *Soil Science Society of America Journal*, 66: 1320-1324.

Hillel, D. (1980). *Fundamentals of Soil Physics*. Academic Press, New York.

Hillel, D. (1982). Introduction to soil physics. Academic Press, San Diego, CA.

Horn, R. and Smucker, A. (2005). Structure formation and its consequence for gas and water transport in unsaturated arable and forest soils. *Soil And Tillage Research*, 82:5-14.

Hugo, L.P., Johann, B., Juergen, G., Hiremagalur, G., Mohammad, J., Victor, M., John, M., Martin, O., and Mohamed, S. (2002). Linking Natural Resources, Agriculture and Human Health: Case Studies from East Africa. LEISA *Magazine supplement*. 17-20. Human kind's foundation for survival. *Journal of Soil and Water Conservation* 58: 1-8.

Igwe, C. A. and Obalum S.E. (2013). Micro aggregate stability of tropical soils and its role on soil erosion hazard prediction. Advance in agro – physical research, Prof. Stanislaw Grundas (ed), ISBN: 978-953-51-1184-9,

Igwe, C. A., Akamigbo, F. O. R. and Mbagwu, J. S. C. (1995). Physical properties of soils of southeastern Nigeria and the role of some aggregating agents in their stability. *Soil Science,* 160: 431-440.

Ike, I.F. and J.A. Aremu, (1992). Soil physical properties as influenced by tillage practice. *In*: International Board for Soil Research and Management (IBSRAM). *Soil Management Abstract*. 4(2): 15. 55 Indicators of Soil Health. CAB International, Wallingford, **p1–28**.

Islam, K. R. and Weil, R. R. (2000). Land Use Effects on Soil Quality in a Tropical Forest ecosystem of Bangladesh. *Agriculture Ecosystem and Environment, 79(1): 9-16*.

Islam, K.R., Kamaluddin, M., Bhuiyan, M.K., Badruddin, A., (1999). Comparative performance of exotic and indigenous forest species for tropical semi-evergreen degraded forest land reforestation in Bangladesh. *Land Degradation and Development,* 10: 241–249.

Iwara, A. I., Ewa, E. E., Ogundele, F. O., Adeyemi, J. A., and Otu, C. A. (2011). Ameliorating Effects of Palm Oil Mill Effluent on the Physical and Chemical Properties of Soil in Ugep, Cross River State, South-Southern Nigeria**.** *International Journal of Applied Science and Technology, 1*(5), 106-112.

Jabro J. D, Stevens W.B, Evans, R.G, and Iversen W.M. (2009). Tillage effects on physical properties in two soils of the Northern Great Plains. *Applied Engineering in Agriculture* **25**, 377-382.

Jagtap, S. S. (1995). Environmental characterization of the moist lowland savanna of Africa. In: Kang, B. T., Akobundu, I. O., Manyong, V. M., Carsky, R. J., Sanginga, N. and Kueneman, E. A. (editors), moist savannas of Africa: Potentials and constraints for crop production. Proceedings of an IITA/FAO Workshop held from 19-23 September 1994, Cotonou, Republic of Benin, pp.13-30

Jastrow, J. D., Boutton, T.W., Miller, R.M., (1996). Carbon dynamics of aggregate-associated organic matter estimated by carbon-13 natural abundance. *Soil Science Society of America Journal,* 60, 801–807.

Jastrow, J. D., Miller, R.M., (1998). Soil aggregate stabilization and carbon sequestration: Feedbacks through organomineral associations. In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), Soil Processes and the Carbon Cycle. CRC Press, New York, pp. 207–224.

Jha, C.S. and Singh, J.S. (1990). Composition and dynamics of dry tropical forest in relation to soil texture. *Journal of Vegetation Science,* **1**: 609-614.

Johnson, D. W. (1992).Effect of forest management on soil carbon storage. *Water Air Soil Pollution*, 64:83-120

Johnson. D.W., Cole D.W. and Gessel, S.P. (1979). Acid precipitation and soil sulfate adsorption properties in a tropical and in a temperate forest soil. *Biotropica*, 11:38-42.

Jones, J.B. (2003). *Agronomic Handbook: Management of Crops, Soils, and Their Fertility*. Boca Raton, FL, USA: CRC Press LLC. 482.

Jordan, C.F. (1993). Ecology of tropical forests. pp.165-195. BSI (British standards institution *In*: L. Panxel (Ed.). *Tropical Forestry Handbook.*

Kahm, M., Avdou, M., Chude, V., Wiesler, F. and Horst, W.J. (2002). Mobilization of phosphorus contributes to positive rotational effects of leguminous cover crops on maize grown on soils from northern Nigeria. *Journal of Plant Nutrition and Soil Science,* 165: 566-572.

Kaihura, F.B.S., Kullaya I.K., Kilasara, M., Aune, J.B., Singh, B.R., and Lal, R. (1999). Soil quality effects of accelerated erosion and management systems in three eco-regions of Tanzania. *Soil and Tillage Research,* 53(1): 59-70.

Kamara, C.S. and Haque, I. (1992). Physical properties of vertisols and their implications for management: A review.PSD working document No. B7. International Livestock Center for Africa (ILCA), Addis Ababa, Ethiopia.

Kang, B.T., Juo, A.S.R., (1986). Effect of forest clearing on soil chemical properties and crop performance. In: Lal, R., Sanchez, P.A., Cummings, Jr., R.W. (Eds.), Land Clearing and Development in the Tropics. Belkema, Rotterdam, pp. 383–394.

Kang, G.S., Beri, V., Sidhu, B.S., & Rupela, O.P. (2005). A new index to assess soil quality and sustainability of wheat-based cropping systems. *Biology and Fertility of Soils*, 41: 389-398.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F. and Schuman, G.E. (2001).Soil quality: A concept, definition and frame work for evaluation. *Soil Science Society of America Journal*, 61:4-10.

Karlen , D. L ., Andrews, S.S. and Doran, J.W., (2001). Soil quality: current concept and applications. *Advances in Agronomy* 74: 1-40

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F., Harris and G.E. Schuman (1997). Soilquality: a concept, definition, and framework for evaluation. *Soil Science Society of America Journal,* 61: 4–10.

Karlen, D. L., Andrews, S. S. and Doran, J. W. 2011. Soil quality: *Current Concepts and Applications Advances in Agronomy* 74: 1-40.

Karlen, D. L., Doran, J. W., Weinhold, B. J. and Andrews, S. S. 2003. Soil quality: Human kind'sfoundation for survival. *Journal of Soil and Water Conservation* 58.

Kemper, W. D., Rosenau, R. C. (1986). Aggregate stability and size distribution. In: A. Klute (ed). Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. *American Society of Agronomy*, Madison, WI, USA,: 425-444.

Keshava, K., Kumar, P. L. and Raghu- Babu, K. (2015). Evaluation of land use land cover for potential town planning using remote sensing and GIS techniques around kadapa Mandal, Y.S.R district, Andhra Pradesh, India.

Khan, F., Ahmad, W., Bhatti, A.U., Khattak R.A. and Shafiq M.. (2004). Effect of soil erosion on chemical properties of some soil series in NWFP. *Science Technology and Development*, 23(4): 31-35.

Killic, C Kilic S and Kocyigit, R. (2012) Assessment of spatio variability of soil properties in area under different land uses. *Bulgarian Journal of Agricultural Science*, 18:722-198

Kimmins, J.P., (1997). Forest ecology: *A Foundation for Sustainable Management, Second Edition*. New Jersey. 596.

Kirchhof, G. and Salako, F. K. (2000). Residual tillage and bush-fallow effects on soil properties and maize intercropped with legumes on a tropical Alfisol. *Soil Use and Management*, 16; 183-188.

Klute, A. (1965). Water holding capacity. pp. 273-278. *In*: C.A. Black (Ed.). Methods of soil analysis. Agron. Part I, No. 9, *American. Society of Agronomy*. Madison, Wisconsin, USA.

Klute A (1986). Method of soil analysis. Part 1(2nd ed) American society of agronomy, Madison,WI klute (1986) water retention : laboratory method , and a klute edition method of soil analysis .part 1 physical and mineralogical method 2nd edition . *American Society of Agronomy*, madison WI page 635-662

Kowal, J. M. and Knabe, D. T. (1970). An Agroclimatological Atlas of the Northern States of Nigeria. Ahmadu Bello University, Zaria Nigeria. P 111

Krull E, Baldock J, and Skjemstad, J. (2001): Soil texture effects on decomposition and soil carbon storage. NEE Workshop Proceedings, 18-20 April 2001 CRC for Greenhouse Accounting, CSIRO *Land and Water Australia*.

Lal, R. and Stewart, B.A. (1995). Soil Management: Experimental Basis for Sustainability and Environmental Quality. *Advances in Soil Science*, CRC Press, Boca Raton, Florida.

Lal, R. (1996). Deforestation and Land Use Effects on Soil Degradation and Rehabilitation in Western Nigeria. I. Soil Physical and Hydrological Properties. *Land Degradation and Development,* 7: 19-45.

Lal, R. (1997a). Deforestation, tillage and cropping systems effects on seepage and runoff water quality from a Nigerian Alfisol. *Soil and Tillage Research,* 41: 261-284.

Lal, R. (1997b). Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. I. Crop yield and soil physical properties. *Soil and Tillage research,* 42: 145-160.

Lal, R. (1997c).Soil degradative effects of slope length and tillage methods on Alfisols in western Nigeria. 3. Soil Physical properties. *Land Degradation and Cover.* 43: 143-158.

Lal, R., Peter, R.H., Uphoff, N. and David, O.H. (2004). Reconciling food security with Environmental Quality through no-till farming. In: Sustainable Agriculture and the International Rice-Wheat system. Marcel Dekker, Inc. New York. 495-511.

Lal, R. (2001). Managing world soils for food security and environmental quality. *Advances in Agronomy,* 74: 155-192.

Lal, R. (2004). Carbon sequestration in dry land ecosystems. *Environmental Management*, 33:528-544.

Lal, R., and Puget, P. (2005). Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil and Tillage Research*, 80: 211-213.

Land used, and land used change and forestry (LULUCF) (2009) glossary of climate change acronyms UNFCCC web site 2009

Landon, J.R., (Ed.). (1991). Booker tropical soil manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. 474.

Larson, W. E. and Pierce, F. J. (1992). Soil loss tolerance: maintenance of long term sol productivity. *Journal of Soil and Water Conservation,* 39:136- 138

Larson, W. E. and Pierce, F. J. (1994). The dynamics of soil quality as a measure of sustainable management. Pages 37 - 51 in J. W. Doran, D. C. Coleman, D. F. Bezdicek and B. A. Stewart, eds. Defining soil quality for a sustainable environment. SSSA-Special Publication 35. *Soil Science Society of America,* Madison , WI, USA.

Lawal, H.M., Ogunwole, J.O. and Uyovbisere, E.O. (2009). Changes in soil aggregate stability and carbon sequestration mediated by land use practices in a degraded Savanna Alfisol. *Tropical and Sub-tropical Agroecosystems*, 10:423-429.

Liebig, M.A., Varvel, G. and Doran, J.W. (2001). A simple performance-based index for assessing multiple agro ecosystem functions. *Agronomy Journal*, 93:313-318.

Liebig, M.A., Doran, J.W., and Gardner, J.C. (1996). Evaluation of a field test kit for measuring selected soil quality indicators. *Agronomy Journal*, 88; 683-686.

Lilienfein, J., Wilcke, W. Ayarza, M.A Vilela, L. Lima S.D.C. and Zech, W. (2000). Chemical fractionation of phosphorus, sulphur, and molybdenum in Brazilian savannah Oxisols under different land uses. *Geoderma*, 96: 31-46.

Lindsay, W.A. (1972). Inorganic phase equillibria of micronutrient in soils: Micronutrient in Agriculture. In: Mortvedt, J.J. (Ed.). *Soil Science Society of America Journal*, Madsion, Wisconsin. 41-58.

Lindsay, W.L. and.Norvell. W.A. (1978). Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of American Journal.* 42: 421-428. Madison, Wisconsin.

Maji, A. K., Reddy, G.P.O, Thayalan S. and Walke, N. J. (2005). Characterization and classification of land farms and soils over Basalthi terrain in sub-humid tropics of Central India. *Journal of Indian Society of Soil Science* 53(2): 154-162.

Malo, D.D., Schumacher, T.E., and Doolittle, J.J. (2005). Long-term cultivation impacts on selected soil properties in the northern Great Plains. *Soil and Tillage Research.* 81: 277-291

Martinez Trinidad S., Cotter, H and Cruz Cardenas G (2012). The aggregate stability indicator to evaluate soil spatio temporal change in a tropical dry ecosystem. *Journal of soil science and plant nutrition .12(2)363-377*

Materechera, S. A., Mkhabela, T. S. (2001). Influence of land-use on properties of a ferralitic soil under low external input farming in southern Swaziland. *Soil and Tillage Research, 62*: 15-25.

Matus, F. Amigo, X., and Kristiansen, S. A. (2007). Aluminum stabilization control organic carbon level in Chilean volcanic soil. *Geoderma*, 132:158-168.

Mayer, J., Buegger, F., Jensen, E.S., Schloter, M., (2003). Residual nitrogen contribution from grain legumes to succeeding wheat and rape and related microbial process. *Plant and Soil*, 255, 541-554.

Mbagwu, J.S.C and Bazzoffi ,P.P (1998). Soil characteristics related to resistance of breakdown of dry aggregate by water drops. *Soil and Tillage Research*, 45:132-145.

McCulley, R.L., Archer, S.R., Boutton, T.W., Hons, F.M., Zuberer, D.A., (2005). Soil respiration and nutrient cycling in wooded communities developing in grassland. *Ecology*, 85, 2804–2817

McRae, R.J., and G.R. Mehuys (1988). The effect of green manuring on the physical properties of temperate-area soils. *Advances in Soil Science*, 3: 71-94.

Meek, B.D., Rechel, E.R. Carter, L.M. and Dejar, W.R. (1992). Bulk density of sandy loam traffic, tillage and irrigation method effects. *Soil Society of American Journal*. 56; 563-565.

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

Mesfin, A. (1996). The challenges and future prospects of soil chemistry in Ethiopia. Pp 78-96. in: Teshome Yizengaw, Eyasu Mekonnen and Mintesinot Behailu (Eds.). *Proceedings of the 3rd Conference of the Ethiopian Society of Soil Science (ESSS).* Feb. 28-29, 1996 Addis Ababa, Ethiopia: Ethiopian Science and Technology Commission. 272.

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

Midkiff, D.V., Frye, W.W. and Blevins. R.L. (1985). Soil erosion effects on soil properties and crop yield in farme’s fields in Kentucky during 1983-84. American Society of Agronomy, Madison, WI, USA. 209p. mountain ecosystems. *Ecologie Soeiete Francaised’ Ecologie; Paris; France* 29 (1-2): 393-398.

Mikha, M M and Rice C W (2004). Tillage and manure effect on soil aggregate associated with carbon and nitrogen. *Soil Science Society of American Journal* 52:1133-1141.

Miller, R.W. and Donahue, R.L. (1995). *Soils in our Environment, 7th Edition.*, Englewood Cliffs, New Jersey: Prentice Hall Inc. 649.

Mohammed A, Leroux, P.A.L., Barker, C.H. and Heluf G. (2005). Soils of Jelo micro-catchment in the Chercher highlands of Eastern Ethiopia: I. Morphological and physiochemical properties. *Ethiopian Journal of Natural Resources*, 7(1): 55-81.

Mokwunye, A.U., (1978). The role of inorganic fertilizers in the chemical degradation of Nigerian Savannah soils Samaru Conference Paper 14. Expert evaluation on methodology for assessing soil degradation. FAO, Rome.16.

Monges, A Magnachew, M and Yimah, F (2013). Land use effect on soil quality indicator .A case study of Abo Wansho southern Ethiopia *.Applied and Environmental Soil Science*, 20:40-45

Mostafa, E., Mehdi E., Majid, B., Hamed, F. and Mahboub. S. (2008). Effect of Land Use Change on Selected Soil Physical and Chemical Properties in North Highlands of Iran. *Journal of Applied Sciences, 8: 496-502.*

Murphy, J. and Riley, J. P. (1962). A modified single solution method for the determination of phosphorous in natural water. Analytical Chemistry ACTA. 27: 31 – 36.

Murphy, P.G. and Lugo, A.E. (1986). Ecology of tropical dry forests. *Annual Review of Ecology and Systematics,* **17**: 67-88.

Nardi, S., Cocheri, G., and Agnola, G. (1996). Biological activity of humus. In: Piccolo, A. (Ed.), Humic Substances in Terrestrial Ecosystems. Elsevier, Amsterdam, 361–406.

Nega, E., and Heluf, G. (2013). Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in senbat Watershed, Western Ethiopia. *Asian Research Publishing Network Journal of Agricultural and Biological Science,* 8(3): 206-212

Nelson, D.W. and L.E. Sommers (1982). Total carbon, organic carbon and organic matter In: AL. Page et al. (ed.). Methods of Soil Analysis, Part 2, 2nd ed. Agron. Mongr. 9, ASA and SSSA, Madison, W1. p539-577.

Neufeldt, H., Ayarza, M.A., Resckc, D.V.S., Zech, W. (1999). Distribution of water-stable aggregates and aggregating agents in Cerrado Oxisols. Geoderma. 93, 85-99. Nigeria, held at University of agriculture, Markurdi, 5-9, December, 2006. Pp 54-64.

Noellemeyer, E., Frank, F., Alvarez, C., Morazzo, G., Quiroga, A. (2008). Carbon contents and aggregation related to soil physical and biological properties under a land-use sequence in the semiarid region of central Argentina. *Soil and Tillage Research*, 99; 179-190.

Nortcliff, S. (2002). Standardization of soil quality attributes. *Agriculture, Ecosystems and Environment,* 88: 161–168.

Oades, J. M. (1984). Soil organic matter and soil structural stability: mechanism and implication for management. *Plant and soil,* 76:319-337

Oades, J. M. (1986).Association of colloidal materials in the soils. XIII congress of ISSS, Humburg, v VI, PP. 660-674

Obi, M. E. (1982) Runoff and soil loss from an oxisols in south eastern Nigeria under various management practices .*Agricultural Water Management*, 5:193-203

Odunze, A.C., Iwuafor, E.N.O. and Chude V.O. (2002). Maize/herbaceous legume intercrops And soil properties in the Northern Guinea Savanna zone, Nigeria. *Journal for Sustainable Agriculture,* 20: 15-25. Harworth press, Inc.

Odunze, A. C. (2003). Effect of forage legume incorporation on selected soil chemical properties in the northern guinea savannah of Nigeria. *Journal for Sustainable Agriculture*, 22 (1): 101-112.

Odunze, A.C., Kureh, I. (2006). Land use limitations and Management Option for a Savanna Zone Alfisols Proceedings of the 30th Annual conference of the *Soil Science Society of Nigeria*, held at University of agriculture, Markurdi, 5-9, December, 2006. Pp 54-64.

Odunze, A. C. (2006). Soil properties and Management Strategies for some sub humid Savanna zone Alfisols in Kaduna State, Nigeria. *Samaru Journal of Agricultural Research*, 22: 3-14

Odunze, A.C., J. Wu, S. Liu, H. Zhu, T. Ge, Y. Wang, and Q. Luo (2012). Soil quality changes and quality status: A case study of the subtropical China Region Ultisols. *British Journal of Environment and Climate Change*, 2(1): 37-57.

Odunze ,A.C.,Ebireri, O.F.,Ogunwole, J,O., Tarfa, B.D., and Eche, N,.M (2013). Effect of tillage and fertilizer on soil quality and yield of maize in an alfisol of a northern guinea savanna of Nigeria. *Journal of Agriculture and Biodiversity Research 167-177 2013*

Odunze A.C (2015). Soil conservation for mitigation and adaption to a changing climate: sustainablesolutions in the Nigerian savanna ecology *International Journal of Plant and Soil Science,* 8(4):1-12, 2015

Odunze A.C., Musa, Y.D and Abdulkadir A. (2017) Soil organic carbon concentrations and stocks under maize/legume cropping system in alfisols of a savanna zone, Nigeria. *British Journal of Applied Science and Technology 21(1): 2017*

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 a South-Southern Nigeria. *African Journal of Environment, Pollution and Health, 7*(2): 47-51

Offiong, R.A. and Iwara, A.I. (2012). Quantifying the Stock of Soil Organic Carbon Using Multiple Regression Model in Fallow Vegetation, Southern Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 5(2): 166-172.

Oguike, P C and Mbagwa ,J S C.(2009) variations in some physical properties and organic matters content of soils of coastal plain sand under different land use types .*World Journal of Agricultural Science, 5:63-67.*

Ogunwole, J.O. and Ogunleye, P.O (2004). Surface aggregation, trace, and heavy metal environment under long-term application of farmyard manure and mineral fertilizers contamination in soil. *Soil Science and Plant Analysis*, 36(11 and 12): 1506-1516.

Ogunwole, J. O. And Ogunleye P. O. (2005). Influence of long term application of organic and mineral fertilizers on quality of a savannah Alfisol. *Journal for Sustainable Agriculture*, 26 (3): 5-14.

Ohu, I.O and Folorunsho, O.A. (1989). The effect of Machinery Traffic on the PhysicalProperties of a Sandy loam soil and the Yield of Sorghum in North-Eastern Nigeria. *Soil and Tillage Reseach*, 13:399-405.

Oikeh, S. O., Chude, V. O., Carsky, R. J., Weber, G. K. and Horst, W. J. (1998). Legume rotation in the moist tropical savanna: Managing soil nitrogen dynamics and cereal yields in farmers' fields. Experimental Agriculture. *Soil Physical Conditions in Nigerian Savannas and Biomass Production*, 34: 73- 83

Okai, I. A., Ramalan, A.A., Adeoye, K.B. (2001). Infiltration characteristics of soils As related to other soil physical properties of soil subgroup in Kadawa Research Station of Nigeria, *Nigerian Journal of Soil Research*, 1: 8 – 11.

Oldman, L.R., (1993). The extent of human induced soil degradation. Annex 5- World map of the status of human induced soil degradation. An explanatory note ISRIC. Wageningen.Cf: Steiner, K.G., 1996 (Ed.). Cause of soil degradation and soil development approach to soil management. Margrafvelag, Weikersheim, Germany. 95.

Olsen, S. R. and Sommers, L. E. (1982). Phosphorus In: Page A.L. et al (eds.), Methods of soil Analysis. Part 2.Agronomy monograph 92nd edition p. 403- 430. Madison, Wisconsin.

Oluwasemire, K. O. and Alabi S O (2004) Ecological impact of changing rainfall pattern, soil process and environmental pollution in Sudan and northern guinea savanna agro ecological zones of Nigeria. *Soil Resources* 5 pp 23-31.

Opara, C. C. (2009) Soil micro aggregate stability under different land use types in south eastern Nigeria .*Catena*, 79:103-112

Osakwe, U. C. (2010). Physical characterization of water stable aggregate in forest and cultivated soil of southern Nigeria .unpublished m.sc thesis .department of soil science, university of Nigeria Nsukka. Nigeria.

Osakwe, S. O. (2014) Physico-Chemical Properties and Fertility Status of Soils under Different Land use Types in Bauchi State. *International Journal of Soil Science*, 2(4): 314 -315.

Osakwe, U.C (2014) effect of land use on chemical properties and soil micro aggregate stability indices in the tropics. Proceeding of the 38th annual conference of the *Soil Science Society of Nigeria*, 2(4): 214 -215

Osman, K. T. (2013) Soil properties and management published by springer science and business media dordreched, the Netherlands *European Journal of Soil Science,* 29 page 607

Papendick, R.I., Parr, J. (1992). Soil quality the key to a sustainable agriculture. *American Journal Alternative to Agriculture*, 7: 2–3.

Parr, J.F., Papendick, R.I., Hornick, S.B. and Meyer R.E. (1992). Soil quality: attributes and relationship to alternative and sustainable agriculture. *American Journal Alternative Agriculture*, 7**:** 5–11.

Perfect, E., Kay, B.D., Ferguson, J.A., da Silva, A.P., Denholm, K.A., (1993). Comparison of functions for characterizing the dry aggregate size distribution of tilled soil. *Soil and Tillage Research*, 28; 123-139

Peterken, G. F., (1974). A method for assessing woodland flora for conservation
using *Indicator Species Biological Conservation,* 6: 239-245.

Philip, J. R. (1957). The theory of infiltration: Sorptivity and algebraic equations. *Soil Science*, 84: 257-264.

Pietro, A. and Placido, L. (2011). Three dimensional representation of geochemical data from a Reubens, B., Achten, W.M.J., Maes, W.H., Danjon, F., Alerts, R., Poesen, J. and Muys, B. (2010). More than Biofuel J*atropha curcas* L. Root system symmetry and potential for soil erosion control. *Journal of Arid Environment*,10:10-16.

Putman, J. and Alt, K. (1987). Erosion control: how does it change farm income *Journal of Soil and Water Conservation,* 42(4): 265-268.

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 2006, 1:33-43.regional perspectives. *American Journals Alternative to Agriculture*. 7, 12–16.

Reginold, E. M., Prmod, K. C, Dhyan, S. and Ashokk P. (2007). Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. *Agriculture, Ecosystems and Environment*, 118(1-4), 130-142(Jan 2007)

Reynold, W.D., and Elrick, D.E. (2002). Constant head soil core (tank) method. Pp. In: J.H Dane and G.C. Topp (eds) method of soil analysis, part 4, physical methods. *Soil Science Society of America,* 5; 804-808 Madison, WI.

Rhoades, J. D. (1982). In: page A.K, Miller R.H. and Kenny D.R. (eds). Methods of soil analysis, part 2, chemical and mineralogical properties second edition. *Agronomy,* 9: 159.

Riffaldi, R.. S.,Saviozzi, A. Lev-Miazi, R. and Cardelli, R. (2002). Biochemical properties of mediteranean soil as affected by long term crop management system. *Soil and Tillage Research* 67:109-114.

Riley, J. 2001. The indicator explosion: local needs and international challenges.

Rillig M. C Wright, S. F., and Eviner, V (2002). The role of arbusculer mycorrhizal fungi and glomalin in soil aggregation: comparing effect of five plant species. *Plant and Soil*, 238: 325-333.

Rillig, M.C. (2004). Arbuscular mycorrhizae, glomalin, and soil aggregation. *Canadian Journal of Soil Science,* 84(4): 161-164.

Rillig, M.C., S.F. Wright, K.A. Nichols, W.F. Schmidt, and M.S. Torn. (2001). Large contribution of arbuscular mycorrhizal fungi to soil carbon pools in tropical forest soils. *Plant and Soil*, 233(2):167–177.

Roamig, D.E., Garlynd, M.J., Harris, R.F., McSweeney, K., (1995). How farmers assess soil health and quality. *Journal of Soil and Water Conservation*, 50; 229–236.

Roamig, D.E., Garlynd, M.J., Harris, R.F., (1996). Farmer-based assessment of soil quality: A soil health scorecard. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. *Soil Science Society of America*, Special Publication 49, Madison, WI, pp. 39–60.

Rowell, D.L., (1994). Soil science: *Methods and Applications.* England, UK: Addison Wesley Longman Singapore Publishers (Pte) Ltd. 350.

Saikh, H., Varadachari, C. and Ghsh, K. (1998a). Change in carbon, nitrogen and phosphorus level due to deforestation and cultivation. A case study in Simplipal National park, India. *Plant and Soil,* 198: 137-145. 57

Saikh H., Varadachari, C. and Ghsh, K. (1998b). Effect of deforestation and cultivation on soil CEC and content of exchangeable bases. A case study in Simplipal National park, India. *Plant and Soil,* 204: 67-75.

Salako F. K., Babalola, O., Hauser, S. and Kang, B. T. (1999). Soil macro aggregate stability under different fallow systems and cropping intensities in southwestern of Nigeria 16: 41-47.

Salako F. K., Hauser, S., Babalola, O. and Tian, G. (2001). Improvement of the physical fertility of a degraded Alfisol with planted and natural fallows under humid tropical conditions. *Soil Use and Management*, 17: 41-47.

Salako, F. K., Tian, G. and Kang, B. T. *(*2002). Indices of root and canopy growth of leguminous cover crops in the savanna zone of Nigeria. *Tropical Grasslands,* 36: 33-46

Salako, F. K. and Tian, G. (2003). Management of a degraded Alfisol for crop production in southwestern Nigeria: Effects of fallow, mounding and nitrogen. *Journal for Sustainable Agriculture,* (In press).

Sanchez, P. A., Swaminathan M. S., (2005). Hunger in Africa: the link between unhealthy people and unhealthy soils. *The Lancet,* 365: 442-444

Sanchez, P.A. (1976). *Properties and Management of Soils in the Tropics*. New York, USA: John Wiley and Sons Inc. 618.

Sandor, J.A., Gersper, P.L. and Hawley, J.W. (1986). Soil at prehistoric agricultural terracing sites in New Mexico. I site placement soil morphology and classification Soil. *Science Society of American Journal,* 50: 160-173.

SAS Institute (1997). SAS/ETS User's Guide, Version 6, second Edition SAS Institute Inc., Cary, NC.

Schimel.D.S. (1986). Carbon and nitrogen turnover in adjacent grass-land and cropland ecosystems. *Biogeochemistry,* 2:345-357.

Schipper, L.A. and Sparling, G.P. (2000). Performance of Soil Condition Indicators Across Taxonomic Groups and Land Uses. *Soil Science Society of America Journal, 64:* 300-311.

Schleuß, U., Q. Wu, and H.P. Blume. (1998). Variability of soils in urban and peri urban areas. *Soil and Tillage Research,* 49:65-77

Seeber, J., and Seeber, G.U.H. (2005). Effects of land use changes on humus forms on alpine pastureland (Central Alps, Tyrol). *Geoderma*, 124:215-222

Shepherd, G., Bureh, R.J and Gregory, P.J. (2000). Land Use Affects the Distribution of Soil Inorganic Nitrogen in Smallholder Production Systems in Kenya. *Biology and Fertility of Soils 31:* 348–355.

Shi, L. L., Shan, Z. J., Kong, D. Y. and Cai, D. J. (2006) 'The Health and Ecological Impacts of Organochlorine Pesticide Pollution in China: Bioaccumulation of Organochlorine

Pesticides in Human and Fish Fats', *Human and Ecological Risk Assessment*, 12(2): 402 – 407

Shukla, M. K., Lal, R., & Ebinger, M. (2006). Determining Soil Quality Indicators by Factor Analysis. *Soil and Tillage Research, 87*: 194-204.

Shukla, M.K., Lal, R., Ebinger, M. (2007). Principal component analysis for predicting corn biomass and grain yields. *Soil Science*, 169: 215–224.

Six, J., Elliot E. T. and Paustian, K. (1999) Aggregate and soil organic matter accumulation in cultivated and native grassland soils. *Soil Science Society of American Journal*, 62:1350-1358

Six, J., Elliot, E.T. and Paustian, K. (2002). Soil macro-aggregate turnover and micro-aggregate formation: A mechanism for sequestration under no tillage agriculture. *Soil and Biochemistry*, 32:2099-2103.

Six, J., K. Paustian, E.T. Elliott and C. Combrink, (2000). Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Science Society American Journal, 64:681-689.*

Skerman, P.J. and Riveros, F. (1990). Tropical grasses, Plant production and protection series 23. FAO, Rome.852.

Sopher, C.D. and Baird, J.V. (1982). *Soils and Soil Management, 2nd Edition*., New Jersey**:** Prentice-Hall, Inc.342.

Sparling, G., Parfitt, R. L., Hewitt, A. E., Schipper, L. A. (2003). Three approaches to define desired soil organic matter contents. *Journal of Environmental Quality,* 32: 760-766

Sposito, G. (Ed.), (1989). The Chemistry of Soils. pp. 226-245**.** Oxford Uni. Press, New York. Sumner, M.E., 2000. *Handbook of Soil Science*. Boca Ratory, Florida: CRC Press

Stocking, M. A, (2003). Tropical soils and food security: The next 50 years. Science 302,

Sumner, M.E., (2000). *Handbook of Soil Science*. Boca Ratory, Florida: CRC Press

Suwardji, P. and Eberbach, P. L. (1998).seasonal changes of physical properties of an oxicpaleustalf (red kandasols) after 16 years of direct drilling or conventional cultivation . *Soil and Tillage Research,* 49:65-77

Szabolcs, I. (1969). The influence of sodium carbonate on soil forming processes and on soil properties. Symposium on the Reclamation of Sodic and Soda-Saline Soils, Yerevan1969. *Agro chemistry and Soil Science,* 18: 392.

Tamirat, T. (1992). Vertisols of central highlands of Ethiopia: Characterization and evaluation of phosphorus status. MSc. Thesis, Alemaya University of Agriculture, Alemaya, Ethiopia.144.

Tekalign, T. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No 13. *International Livestock Research Center for Africa*, Addis Ababa

Teklu B. (1992). Intensive training for soil laboratory technicians: Soil analysis on CEC, exchangeable base and calcium carbonate. *National Soil Research Center*, Addis Ababa. Ethiopia.

Thomas, S. J. (2000). Soil fertility evaluation. *Sumner Handbook of soil science* (pp. 159-164), United States of America: CRC presses, LLC.

Thompson, L. M. and Troeh, F. R. (1993). *Soils and Soil Fertility* (5th edition.). Oxford University press.

Tisdale, S.L., Nelson, W.L. Beaton, J.D and Havlin, J.L. (1995). *Soil Fertility and Fertilizer, 5th Edition*. New Delhi, India: Prentice-Hall of India. 684.

Tisdall, J. M., Smith S. E., and Rengassmtn, P. (1997).Aggregation of soil by fungal hypea. *Australian Journal of Soil Science,* 33:55-60.

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

Tisdall, J.M., Oades, I.M. (1980). The effect of crop rotation on aggregation in a red-brown earth. *Australian Journal of Soil Resources*. 18, 423-434.

Topp, G. C., Reynolds, W. D. and Green, R. E. (editors) (1992). Advances in measurement of soil physical properties: Bringing theory into practice. Proceedings of a symposium sponsored by Division S-1 of the Soil Science Society of America in San Anthonio, Texas 21-26 Oct 1990. *Soil Science Society of America Publication,* 30.

Turchenek L.W., and J.M. Oades. (1979). Fractionation of organo mineral complexes by sedimentation and density techniques. *Geoderma,* 21:311-343.

Turner B.L. Moss, R.H and Skole, D.L. (1993). Relation land use and Global land cover change. Stockholm: International Geospher-Biospher Programmed (IGBP) secretariat, Royal Swedish Academy science.

Unger P.W. and Kasper (1994). Aggregate and organic concentration inter-relationships of torrerttic paleustoll. *Soil and Tillage Research*, 42:95-13.

Unger, P.W. (1997). Aggregate and organic carbon concentration inters relationships of a torrerttic paleustoll. *Soil and Tillage Research*, 42, 5-13.

United States Department of Agriculture. (USDA). Natural Resources Conservation Services (1998). Keys to Soil Taxonomy.8th Edition. P 326. Urban forest ecosystem. In: Kimble, J. M., Heath, L. S., Birdsey, R. A.andLal, R.(Eds.), The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect. 347–362.

USDA (United States Department of Agriculture). (1987). *Soil Mechanics Level I-Module 3*: USDA Textural Classification Study Guide. National Employee Development Staff, Soil Conservation Service, USDA

USDA- United State Department of Agriculture (2008). *Soil Quality Indicators*. Retrieved October 17, 2011, from soils.usda.gov/sqi/…/bulk density .soil quality physical indicator sheet.pdf.

Utomo, W. H. and Dexter A R (1982).Changes in soil aggregate water stable induced by wetting and drying cycles in non –saturated soil. *Soil Science,* 33: 623-637.

Van Bavel, C.H.M. (1950). Mean weight diameter of soil aggregates as a statistical index of aggregation. *Soil Science of America Proceedings,* **14**:20-23.

Van Haverse, B. (1983). Soil Bulk Density as influenced by grazing intensity and soil type on a short grass prairie site. *Journal of Range Management,* 5:586-588

Van Veen, J.A., and E.A. Paul. (1981). Organic carbon dynamics in grassland soils. 1. Background information and computer simu-lation. *Canadian Journal Soil Science,* 61:185-201.

Van Veen, J.A., Ladd J.N., and Frisse M.J. l. (1984). Modeling C and N turnover through the microbial biomass in soil. *Plant and Soil* 76:257-274.

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

Wakene N, (2001). Assessment of important physicochemical properties of Dystric Udalf Dystric Nitosol) under different management systems in Bako area, western Ethiopia. *M.Sc.Thesis, Alemaya University, Ethiopia. 93.*

Walkley, A. and Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*,37: 29-38. 58

Wani, S.P., Rupela, O.P. and Lee, K.K. (1995). Sustainable agriculture in the Semi-aid Tropics through Biological nitrogen fixation in grain legumes. *Plant and Soil,* 174: 29-49.

Webb, A.A. and Dowling, A.J. (1990). Characterization of basaltic clay soils (Vertisols) from the Oxford Land System in central Queensland. *Australian Journal of Soil Research* 28(6): 841-856.

Werner, M.R. (1997). Soil Quality characteristics during conversion to organic orchard management. *Applied Soil Ecology* 5:151-167.

White, R. E. (1985). The influence of macrospores on the transport of dissolved and suspended matter through soil. *Advance Soil Science.* 3: 95 – 120.

White, R.E. (1997). *Principles and Practices of Soils Science: The Soil Is The Natural Resource* Uk: Cambridge University Press. 348.

Whitebread, A.M., Lofroy, R.B.D. and Blair. G. J.Y (1998) A survey of impact of cropping on soil physical and chemical properties in northeastern New South Wales. *Australian Journal of Soil Resource,* 36: 669-681.

Wienhold, B. J. Andrews S S and Karlen D. L., (2009). Soil quality: A review of the science and experiences in the USA. *Environment Geochemical, Health*. 26, 89-95.

Wiesmeier, M., Steffens, M., Mueller, C.W., Kolbl, A., Agnieszka, R., Peth, S., Horn, R., Kogel-Knabner, I. (2012). Aggregate stability and physical protection of soil organic carbon in semi-arid steppe soils. *European Journal of Soil Science*, 63: 22-31.

Woldeamlak, B. and Stroosnijder, L. (2003). Effects of agro-ecological land use succession on soil properties in the Chemoga watershed, Blue Nile basin, Ethiopia. *Geoderma*, 111: 85-98.

Yakubu, M. and Ojanuga, A.G. (2009): Pedogenesis, weathering status and mineralogy of the soils on ironstone plateau (laterites), Sokoto, Nigeria. In Fasina, A.S., Ayodele, O.J., Salami, A.E. and Ojeniyi, S.O.(ed). (2009). Management of Nigeria soil resources for enhanced agricultural productivity. Proceedings of the 33rd *Annual Conference of the Soil Science Society of Nigeria* held at University of Ado-Ekiti, Ado-Ekiti, Ekiti State, Nigeria. March 9-13, 2009. PP 26-37.

Yang, X. M and Wander, M. M. (1998).Temporal changes in dry aggregate size and stability: tillage and crop effect on a silty loam mollisol in Illinois. *Soil and Tillage Research,* 49: 173 -183.

Yerima, B.P.K. (1993). Manuals for good laboratory practice. Improvement of soil services for agricultural development. Field document no. 52. Land use planning and regulatory department, Ministry of natural Resources development and Environmental protection /FAO/ Addis Ababa, Ethiopia.

Yihenew, G., (2002). Selected chemical and physical characteristics of soils Adet Research Center and its Testing Sites in North-Western Ethiopia. *Ethiopian Journal of Natural Resources,* 4(2): 199-215

Yoder, R. E, (1936).A direct method of aggregate analysis of soil and a study of physical nature of so erosion loses. *Journal America Society of Agronomy*, 28:337-351

Young, J. L., and . Spycher, G. (1979). Water-dispersible soil organic-mineral particles: 1. Carbon and nitrogen distribution. *Soil Science Society of American Journal*, 43:324-328.

Zech, W. Senesi, N., Guggenberger, G., Kaizer, K., Lehmann, J., Miano, T.M., Miltner, A and Schroth, G. (1997). Factors controlling humification and mineralization of soil organic matter in the tropics. *Geoderma*, 131:153-163

Zhang W.L., Tian Z.X., N. and Zhang, X.Q. (1996). Nitrate pollution of groundwater in northern China. *Agriculture Ecosystems and Environment*, 59: 223–231

APPENDIX 1

. Classification of soil reaction (pH) based on pH (H_2O) and Organic matter

Rating	pH (1:2.5 H_2O)
Very strongly acid	< 4.5
Strongly acid	4.5-5.2
Moderately acid	5.3-5.9
Slightly acid	6.0-6.6
Neutral	6.7-7.3
Moderately alkaline	7.4-8.0
Strongly alkaline	> 8.0

Source: Tekalign (1991)

APPENDX 2 Rating Of Exchangeable Cation

	Ca (cmolkg^{-1})	K (cmolkg^{-1})	Mg (cmoolkg^{-1})	Na (cmolkg^{-1})
Very low	< 2	< 0.2	< 0.3	< 0.10
Low	2–5	0.2-0.3	0.3-1.0	0.1-0.3
Medium	5–10	0.3-0.6	1.0-3.0	0.3-0.7
High	10–20	0.6-1.2	3.0-8.0	0.7-2.0

Very high	> 20	> 1.2	>8.0	> 2.0

Source: FAO (2006) and Hazelton and Murphy (2007)

Appendix 3 show some physiochemical properties in Afaka forest reserve

Parameter	low	Medium	High
Org. C (g kg^{-1})	< 10	10 – 15	> 15
Total N (g kg^{-1}	< 0.1	0.1 – 0.2	> 0.2
Avail. P. (mg kg^{-1}	< 10	10 – 20	> 20
CEC (cmol kg^{-1})	< 6	6 – 12	> 12
Bulk Density (Mg m-3)	≥ 1.4	1.2– 1.4	< 1.2

Source: Enweazor *et al* (1989), Esu (1991),