THE EFFECT OF LAND USE ON SOIL AGGREGATE STABILITY AND SOIL CARBON SEQUESTRATION IN SOME SELECTED SOILS OF SOUTH EASTERN NIGERIA

BY

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Abstract

The Information on the effect of different land use systems on the aggregate stability and carbon sequestration is crucial for the recommendation of efficient land management practices. This study was conducted to evaluate the variation in aggregate stability and carbon sequestration under different land use systems in two agro ecological zones of south eastern Nigeria. The agro ecological zones were derived savannah and rainforest while the land use systems studied were cultivated, excavated, fallow, forest and grazing. The soil samples were collected at a depth of 0-15 cm using transect method and analyzed for particle size distribution, water stable aggregates, mean weight diameter, % aggregate stability, total organic carbon and organic carbon associated with water stable aggregates (4-2 mm, 2-0.25 mm, 0.25-0.053 mm).The data collected were subjected to analysis of variance (ANOVA) in randomized complete block design (RCBD). The results show that land use did not affect particle size distribution and the effect of agro zone on aggregate stability indices(WDC, DR and MWD) was not significant($P<0.05$). However, ASC (aggregated silt + clay) and %AS (aggregate stability) in the derived savannah were 29.5% and 11.7% higher than the rainforest respectively. The MWD was reported to be greater in fallow, forest and grazing than cultivated and excavated. The percentage water stable aggregates were not significantly affected ($P<0.05$) by land use but grazing gave significantly higher values than excavated, cultivated, fallow and forest for 4-2 mm and 2-0.25 mm. The overall result has shown that forest and grazing land use systems are superior in terms of improving soil quality. Therefore, fallow land can be converted to grazing while the addition of organic material is recommended in arable and excavated land use.

Key words: ASC (Aggregated silt+ clay), MWD (mean weight diameter), DR (dispersion ratio), % AS (percentage aggregate stability), WDC (water dispersible clay).

CERTIFICATION

This is to certify that this project titled "The Effect of Land Use on Aggregate Stability and Soil Carbon Sequestration in Some Selected Soils of South Eastern Nigeria" meets the requirement of a final year project and Award of Bachelor of Agriculture (B.Agric) degree of the Federal University Oye Ekiti and approved to have contributed to knowledge.

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DEDICATION

This work is dedicated to Almighty Allah (SWT), for his abundant mercy on the completion of this project.

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CHAPTER ONE

1.0 INTRODUCTION

Aggregate stability is one of the most important factors in soil conservation and maintenance of soil environmental functions. Aggregation affects soil capacity to store and stabilize carbon (Six et al, 2004, Kodesova et al, 2008) as well as soil water storage capacity and distribution in landscape (Scheer et al, 2011; Schmidt et al, 2011; Berhe and Kleber, 2013). Aggregate stability is defined by several intrinsic soil properties (Igwe et al 2009). Various indices have been used in the estimation of aggregate stability of soils such as mean weight diameter(MWD) (Larney, 2008); geometric mean diameter (GMD); water stable aggregates (WSA); aggregate stability index (ASI test) (Trinidad et al 2012).

Soil organic carbon is one of the most important constituents of the soil due to its capacity to affect plant growth as both a source of energy and a trigger for nutrient availability through mineralization is the main source of energy for soil microorganisms, the ease and speed with which soil organic carbon becomes available is related to the soil organic matter fraction in which it resides. It releases nutrients for plant growth, promotes the structure, biological and physical health of soil, and is a buffer against harmful substances. In soil profiles with lower soil organic matter (SOM) content, the main aggregation agents are Fe and Al oxides. The effect of these minerals on aggregate stability has been attributed to structural cementation, and is a subject extensively explored in the literature (Barthes et al 2008, Igwe et al 2009).

Carbon sequestration is the process involved in carbon capture and the long –term storage of atmospheric carbon dioxide (Sedjo, Roger; Sohngen, Brent 2012) or other forms of carbon to mitigate global warming. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels (Hodrien, 2008). According to Lal (2008), the process removes carbon pool and is primarily mediated by plants through photosynthesis where carbon is stored in the form of soil organic carbon. The keys to successful soil carbon sequestration are increased plant growth and productivity, increased net primary production and decreased decomposition (Tieszen 2000).

The changes in land use significantly alter biodiversity and ecosystem functioning across different biomes and continents (Foley et al.2005). Land use changes have a great influence on soil organic matter by affecting its quality attributes and fertility. Soil organic matter is comprised of the product of plant and animal materials that have undergone decomposition processes (Bot and Benites, 2005). According to Nega (2013) the highest organic matter was recorded in the surface soil of forest lands and plantation land and least in arable lands because of tillage practices and crop removal. Land use practices affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations on the rooting zone (Murty *et al.*, 2002). Cultivation of forests soil diminishes soil carbon (C) within a few years of initial conversion (Murty et al. 2002) and substantially lowers mineralizable nitrogen (N) (Solomon et al. 2002).

Micro-aggregate (aggregate < 0.25mm) stability indices serve as sensitive indicators of soil degradation (Boix-fayos, 2001) and are very important in the processes of infiltration, sealing and crust formation, runoff and soil erosion (Levy and Miller, 1997). An assessment of micro-aggregate stability under different land use types in some Nigerian tropical soils revealed the strong dependence of soil micro-aggregation on land use (Opara, 2009). Cultivated soils were more affected by decreasing aggregate stability than uncultivated soils. *Lehtinen* et al. (2014); Oguike (2009) recorded lower stability in continuously cultivated soils with dispersion ratio higher in cultivated soils while clay flocculation index was lower which implies poor stability in cultivated soils. Fallow land (FL) and oilpalm plantation land (OPL) had higher organic carbon OC content compared to cultivated yam plot (YL) and continuous cultivated land (CL) because of the continuous addition of soil organic matter to FL and OPL and subsequent mineralization of the added soil organic matter. Ahukaemere et al., 2012 recorded higher organic carbon in fallow and oil palm plantation soils compared to continuously cultivated soil.

1.1 Problem statement

Aggregate stability is critical for infiltration, root growth and resistance to water and wind erosion. Unstable aggregates disintegrate during rainstorm. Improper land use patterns will lead to breakdown of unstable aggregates, producing finer and more easily transportable particles and micro aggregates.

Water stable aggregate (WSA %) of a paddock will vary before and after cropping, especially for root vegetables. Periodic tillage reduces WSA%. Cropping will in general terms decrease WSA, as well as tillage.

Since industrial revolution which is exacerbated by rapacious urbanization, there has been unusual conversion of natural ecosystem for agricultural use or other uses resulting in depletion of soil organic carbon to about 50 to 100GT of carbon captured from the atmosphere (Lal, 2015). At the global and regional scales, temperature and precipitation are dominant factors affecting soil organic carbon storage, and the soil organic carbon increases with increasing precipitation and decreasing temperature (Herold et al 2014). Grazing not only affects the carbon input by altering plant productivity but also can change soil clay content and soil pH, which affects microbial organic matter decomposition (Dlamini et al. 2016). Many studies have demonstrated that soil organic carbon storage decreases with shift from a natural land use pattern to an artificial land use pattern, and conversely, soil organic carbon storage increases with a shift from an artificial land use pattern to a natural land use pattern (Rabbi , Dalal , et al. 2015).

1.2 Justification

Land use change alters biodiversity and soil quality and thus affects ecosystem functions. Changes in aggregate stability may serve as early indicators of recovery or degradation of soil. Aggregate stability is an indicator of organic matter content, biological activity and nutrient cycling in soil. Greater amount of stable aggregates suggest better soil quality. Stable aggregates can also provide a large range in pore space, including small pores within and large pores between aggregates. Large pores associated with large, stable aggregates favor high infiltration rates and appropriate aeration for plant growth.

Soil organic carbon is the basis of soil fertility. It releases nutrients for plant growth, promotes the structure, biological and physical health of soil, and is a buffer against harmful substances. Organic matter influences soil aggregate stability by binding soil mineral particles and reducing aggregate wettability. It influences the mechanical strength of soil aggregates, which is the measure for the coherence of inter-particle bonds (Onweremadu et al., 2007). Therefore, this study will help in monitoring changes in soil quality and soil use policy.

1.3 General objectives

The main objective of this study is to evaluate the effect of land use on soil aggregate stability and soil carbon sequestration in two agro ecological zones of south eastern Nigeria.

The specific objectives are to determine

- aggregate size distribution of water stable aggregate
- mean weight diameter
- percentage aggregate stability
- micro aggregate stability indices
- soil organic carbon associated with water stable aggregates

CHAPTER TWO

LITERATURE REVIEW

2.1 LAND USE

Land use can be described as a set of technological and biological activities engaged in for economic and social purposes (Fashina 2017). The difference of aggregate stability under different land use patterns is mainly due to the intensity of human disturbance and cultivation. Improper land use patterns will lead to breakdown of unstable aggregates, producing finer and more-easily transportable particles and micro aggregates.

Some of this land use types include; excavated, grazing land, plantation (cocoa), forest, cultivation and fallow.

2.11 soil aggregates and aggregate stability

A soil aggregate is a group of primary soil particles that adhere to one another more strongly than to surrounding soil particles (Follett et al., 2009).

Soil aggregate stability is a fundamental structural property of soil that determines soil's productivity and resistance to erosion and degradation (Six et al, 2000). When soil aggregates breakdown, finer particles are produced which are easily carried away by water flow and wind and which upon sedimentation tend to clog soil pores leading to the formation of soil crust (Yan et al., 2008).

Soil aggregates, the basic units of soil structure, are sensitive to land uses and mediate ant chemical and biological processes in soils (Cates A. M., Ruark M. D., et al, 2016. Stable micro aggregates form macro aggregates via temporary and transient binding agents (i.e. fungal hyphae and roots). The hierarchical order of aggregates might lead to the differences in the distribution and availability of soil organic matter (Trivedi et al, 2015). Soil aggregate stability may be used as an indicator to express the ability of a soil to sustain mechanical breakdown, it is an attribute that is contingent on the shear strength of a soil (Frei et al 2003); on the amounts and forms of organic matter prevalent in a soil (Mbagwu and Piccolo. 2003); on the biochemical composition of plant residues and influences on soil's functional properties like soil permeability (Bronick ., Lal R., 2005); on vegetation cover(Burri , Graf , Boll . 2009) etc. Tillage practice appears to be one major activity that breaks down soil aggregation and so aggregate stability and it was found out that the aggregate stability decreased due to tillage (Holeplass , Singh , Lal, 2004, Khurshid et al 2006).

2.12. Macro aggregates and micro aggregates on different land use

Macro aggregates are a collection of silt/clay particles, micro aggregates and organic matter. Plant roots, mychorrhizae and earthworms are major contributors to the formation of macro aggregates. These larger aggregates have a shorter breakdown time, providing organic matter source for roots, bacteria, and fungi. Macro aggregates comprises all soil aggregates >250nm.

Micro aggregate are composed of smaller building unit that become more complex with increasing size Tisdall and Oades (1982). Micro aggregates are silt and clay particles tightly bound by organic materials. This provides a long-term pool for organic matter. Micro aggregates denote all compound soil structure <250nm. In soil science, pore size is defined as the equivalent pore diameter of ideal capillary pores (Hartge and Horn, 2016), while the IUPAC system refers to the actual size of pores found in chemical compounds.

Micro aggregates are divided into three size classes:

Building units (smaller than 2nm), including the composite building units; small micro aggregates (between about 2nm and 20nm) and large micro aggregates (between about 20nm and 250nm).

According to some research, macro aggregates (>2mm) were abundant in forest soils (41-70%) while micro aggregates (<0.5mm) were abundant in cultivated lands (56-63%). Pined mixed forest contained more macro aggregates in both layers. Macro aggregates in the surface layers contained 14.9 to 24.8 and 5.5 to 20.7 g/kg SOC in cultivated and forest soils respectively, while micro aggregates contained 12.5 to 30.8 and 11.9 to 25.4 g/kg SOC respectively. The forest soils contained more sand (639-834g/kg) and fewer clay particles (49-95 g/kg) than the cultivated soils.

Some researchers reported that micro-aggregation depended strongly on the size distribution of primary particles rather on land use [Leifeld, 2003]. The stability of the aggregates (i.e. degree of resistance against disintegrating forces of water and physical action) is most important factor in the structural behavior of a soil Tamhane et al. (1970). The CFI also is a very good Index for predicting soil erodibility and a good micro-aggregate index. The clay-flocculation index (CFI) is also another index that shows the ability of the soils to resist dispersion in water. Soils high in CFI are well aggregated and will not easily dispersed in water (Igwe et al.,1995). Water dispersible clay (WDC) and the dispersion ratio (DR) being an index from water-dispersible silt and clay and their corresponding total forms have also been successfully used to predict Erosion by water. An assessment of micro-aggregate stability under different land use types in a Nigerian tropical soil revealed a strong dependence of the soil micro-aggregation on land use Obi M.E, 1982. This implies that the agents of stability of micro-aggregate in tropical soils are sensitive to land use. Micro-aggregate stability is a good indicator of the erodibility of tropical soils because of its direct link with silt and clay dispersion.

2.13 Water stable aggregates

Soil water – stable aggregation is an important process for carbon sequestration and is key factor controlling soil sustainability. Water Aggregate stability is a measure of the extent to which soil aggregates resist falling apart when wetted by and hit by rain drops.

Monitoring the water stable aggregate (WSA) of soils will aid soil management decisions. Cropping will in general terms decrease WSA, as does tillage. WSA is positively correlated to clay content and organic content in other words, proactive management of soils with cover crops, for example will have the added benefit of improving soil organic carbon levels, as well as microbial activity. The water stability of micro aggregates depends on the persistent organic binding agents and appears to be a characteristic of the soil, independent of management.

2.2 AGGREGATE SIZE DISTRIBUTION AND STABILITY ON DIFFERENT LAND USE

According to some research done on aggregate size distribution and stability, the results showed that in uncultivated (forest and pasture) soils, the aggregates>0.25mm decreased significantly with cultivation. In the forest and pasture soils, the 4.76 to 0.25mm size aggregates predominantly comprised 83 and 90% respectively. Compared to forest soils, cultivation decreased the water stable aggregate (WSA) proportion of 4.76 to 2.0mm size aggregates in depth 0-20cm by 3.6times; while the decrease was 85% foe 2.0 to 1.0mm size aggregates.

Comparison of cropland and pasture soils followed the pattern observed with forest soils; sowing 4.3 times decrease for 4.76- 2.00mm fraction and 89% decrease for 2.0-1.0mm fraction. However, in the cropland soil, a significantly large proportion of the aggregates were <0.50mm in size. Smaller size aggregates of <1.2mm was found to be a useful indicator of soil degradation (Whalen & Chang, 2002). Loss of the larger aggregate sizes in cropland could also be due to tillage rapidly destroying live and decaying plant roots, fungal hyphae, earthworms and termites.

Soil aggregation is the result of the interaction of numerous physical, chemical and biological factors with intricate feedback mechanism (Six et al., 2004). Understanding the mechanism of soil aggregation is the key to improve soil quality and facilitates to the management of soil biogeochemical processes. Mbagwu and Schwertman suggested that aluminum oxides were more effective in aggregation of gibbsite than iron oxides (Peng et al, 2015). Barthès et al., 2008 reported that Al-containing sesquioxides have a more important role than soil organic matter in the aggregation of tropical soils [Igwe, Zarei, Stahr ., 2009). Peng et al., 2015 found that Fe/Al oxides were likely the major agents in micro-aggregates while SOM plays a primary role in stabilizing the macro-aggregates in Ultisols (Gargiulo ,Mele, Terribile,2013. From the aforementioned reports, it can be seen that these agents vary in their functions in aggregation. As numerous factors are involved soil aggregation, it is usually difficult to distinguish their specific role separately (Gargiulo, Mele, et al.,2013).

Land excavation is a process where trees, shrubs and plants are removed from a certain area. There are several different methods for land clearing and excavation, and the best method to use is also dependent on the condition of the land as well as the intended use after the clearing and excavation is completed. Research has shown that aggregate stability was much lower in deep than surface soil layers, likely linked to lower soil organic carbon (SOC) and root mass density (RMD) (Alexia S, Ivan P et al., 2017).

Soil properties vary in vertical and lateral directions and such variation follow systematic changes as a function of the landscape position (slope), soil forming factors and/or soil management practices (land use) (Amusan et al., 2006). The research showed that the high mean weight diameter MWD under oil palm plantation (OP) was perhaps as a result of its high OC content which upon decaying may have produced polysaccharides which served to bind the micro aggregates into macro aggregates (Golchin et al, 1995). Contrarily, the low MWD observed under C may be the result of its low OC content not able to release enough polysaccharides and plant exudates necessary for binding the micro aggregates into water stable macro aggregates. The mean weight diameter and water stable aggregates were greater in the pasture and forest soils in comparison with the cultivated soils and did not change with the depth for each land use type (Mostafa et al., 2008).

2.21Factors affecting stability of soil aggregates

Inherent – aggregation and stability of soil aggregates are affected ny predominant type and amount of clay, adsorbed cations, such as calcium and sodium and iron oxide content. Expansion and contraction of clay particles as they become moist and then dry can shift and crack the soil mass and create aggregates or by reak them apart. Calcium, magnesium, iron and aluminium stabilize aggregates via the formation of organic matter- clay bridges. In contrast, aggregate stability decreases with increasing amounts of exchangeable sodium. Dispersion is promoted when too many sodium ions accumulate between soil particles.

Dynamic – aggregate stability is highly dependent on organic matter and biological activity in soil, and it generally increases as they increase. Fungal hyphae, thread-like structures used to gather resources, bind soil particles to form aggregates. Soil particles are also aggregated and stabilized by organic ''glues'' resulting from biological decomposition of organic matter. Soil biota help create aggregates and use them as habitat or refugia to escape predation.

The simplest solution is to grow a green manure cover crop, or to apply organic materials to the paddock (e.g. composts, manure, bio solids). Cropping will in general terms decrease WSA, as does tillage. WSA is positively correlated to clay content and organic content in other words, proactive management of soils with cover crops, for example will have the added benefit of improving soil organic carbon levels, as well as microbial activity.

2.22 Practices that leads to poor aggregate stability

- Tillage methods and soil disturbance activities that breakdown plant organic matter, prevent accumulation of soil organic matter and disrupt existing aggregates
- Cropping, grazing or other production systems that leave soil bare and expose it to the physical impact of raindrops or wind- blown soil particles
- Using of pesticides harmful to beneficial soil microorganism
- Removing sources of organic matter and surface roughness by burning, harvesting or otherwise removing crop residues.

2.3 SOIL ORGANIC CARBON

Carbon storage in soils can be influenced by agricultural management practices. Forest and alley cropping can store large quantities of carbon C in soils. According Sundermier et al. (2004), forest sequester 10.6% as well as carbon dioxide as was released in United States by combustion of fossil fuel.

Many studies have demonstrated that soil organic carbon storage decreases with shift from a natural land use pattern to an artificial land use pattern, and conversely, soil organic carbon storage increases with a shift from an artificial land use pattern to a natural land use pattern (Rabbi , Dalal , et al. 2015). Climate and soil properties limit the positive effects of land use reversion on carbon storage, Guo, Gifford (2002). Soil carbon stocks and land use change: a meta-analysis. Global Change Biology 8: 345-360.). Previous studies showed that tillage adversely affects carbon storage in soils (Anikwe et al, 2003). Similarly, Batiano et al. (2007) in a study reported rapid decline of SOC levels with continuous cultivation. For sandy soils they found that average annual losses may be as high as 4.7% whereas as with sandy loam soils, losses were lower with an average of 2%. Some studies have also shown that the natural undisturbed forest stored the highest quantity of carbon. The amount of organic matter is normally highest in the forest soil compared to continuously cultivated soil (Funakawa *et al.*, (1997); Gebrelibanos and Mohammed.,2013). Litter fall is the major contribution of soil organic matter in the forest ecosystem. Conversion of the natural forest into continuous cultivation had resulted in significant reductions of both the concentration and stock of organic matter. Lobe *et al.*, (2001) reported that the organic matter content in soils decreased rapidly in the first few years they were cultivated.

Fallow land (FL) and oil palm plantation land (OPL) had higher organic carbon OC content compared to cultivated yam plot (YL) and continuous cultivated land (CL) because of the continuous addition of soil organic matter to FL and OPL and subsequent mineralization of the added soil organic matter. Ahukaemere et al., 2012 recorded higher organic carbon in fallow and oil palm plantation soils compared to continuously cultivated soil.

High fractions under alley cropping and grazing land uses are attributable to effective rooting network system of vegetation which allowed for high concentration of clay fraction in the soil (Okonkwo et al. 2011). Continuous cultivation and cropping increased soil compaction and hindered root proliferation which limited soil productivity (Anikwe et al. 2007). All organic carbon in soils is located within the pores between mineral particles either as discrete particle or as molecules absorbed onto the surface of these mineral particles (Krull et al. (2001).

Forested soils maintained high levels of organic matter comparable to soil from the continuously cultivated fields, which exhibited lower than those in soil kept under prolonged fallow (Fuller and Anderson, 1993; Sanchez et al., 1983). Conversion of forest to cultivated land causes an appreciable change in organic matter content resulted in nutrient imbalances, and reduction in water holding capacity, iron, aluminum, nitrogen, calcium, magnesium, potassium, phosphorus, and cation exchange capacity (Jha et al., 1976; Brown and Lugo, 1990). It has been reported that the conversion of forest to other landuse caused a decline in soil organic carbon (Allmaras *et al.*, 2000). According to Griffits *et al.*, (2001), The SOC pool is highly reactive and sensitive to natural and anthropogenic perturbations.

Therefore, land use change from natural to agricultural ecosystems depletes the SOC pool over time, generally in the order cropland > grazing land > forest (Lal, 2003). The change from natural ecosystems to croplands induces changes in the balance of Carbon inputs and turnover rates; generally. The annual additions of organic matter are reduced when the forest is cleared for cultivation and when small scale farming transforms into large scale cash crop cultivation (Craswell and Lefroy, 2001; Follett et al., 2005).

2.31 How is soil organic matter different from soil organic carbon?

Soil organic carbon (SOC) refers only to the carbon component of organic compounds. Soil organic matter is difficult to measure directly, so laboratories tend to measure and report soil organic carbon (Griffin et al, 2013).

2.32 Effect of land use on aggregate associated carbon

Soil aggregate stability is often regulated by factors such as soil organic matter, microbial biomass, iron and aluminum oxides and other clay minerals. Carbon that enters smaller aggregates were enriched with soil organic carbon. Onwemadu et al., 2010. Observed differences in the distribution of carbon fractions in soil aggregate with concentration of colloidal organic materials being higher in water stable aggregate. Organic matter improves soil aggregation. Organic matter influences soil aggregate stability by binding soil mineral particles and reducing aggregate wettability. It influences the mechanical strength of soil aggregates, which is the measure for the coherence of inter-particle bonds (Onweremadu et al., 2007).

The microbial decomposition of aggregate-associated organic matter might lead to aggregate disintegration and thus initiate aggregate turnover (*Six* et al., 2000). *Al-Kaisi* et al. (2014) found that aggregate stability and moisture content are highly correlated with organic carbon content, and the decay rate of both macro- and micro-aggregates is highly influenced by the intensity of tillage. In soil profiles with lower soil organic matter (SOM) content, the main aggregation agents are Fe and Al oxides. The effect of these minerals on aggregate stability has been attributed to structural cementation, and is a subject extensively explored in the literature (Barthes et al 2008, Igwe et al 2009). However in soils with lower clay and Fe oxide content, aggregate stability is related to SOM (Six et al 2002).

Micro-aggregate (< 0.25mm) are composed of diverse mineral, organic and biotic materials that are bound together during pedonesis by various physical, chemical and biological process (Kai *et al.,* 2017). Levy and Miller (1997) indicated that breakdown of unstable aggregates results in the collapse of soil pores and production of finer particles and micro-aggregates. The stability of micro-aggregates seems to be dependent on changing environmental conditions, *like* moisture, pH, redox-potential, and ionic strength (Leifeld, 2003). Reduction in soil organic carbon (SOC) changes the distribution and stability of soil aggregates (Singh 1996) making the soils more susceptible to erosion (Elliott., 1993; Six et al., 2000).

2.4 RELATIONSHIP BETWEEN CARBON CONTENT AND AGGREGATE STABILITY

The relationship between C content and aggregate stability was observed in soils in tropical climate in different degrees of weathering (Gajic et al 2006, Six et al 2004, Inda Junior et al 2007, Li et al 2007). The SOM effect on aggregation has traditionally been attributed to the inner sphere complexes between the carboxyl groups and cations of the mineral structure by the ligand exchange mechanism (Chorover and Amistadi 2001, Mikutta et al 2011). In mineral soils, the positive effect of SOM on aggregation is usually related to its content (Six et al 2002, Inda Junior et al 2007, Kodesova et al 2009). However, the role of SOM chemical composition on aggregate stability has been less investigated. Some studies have indicated that in aerobic soils, the surface of Fe oxides can interact directly with carbohydrate-like structures that are more labile compounds, and not only via ligand exchange with carboxyl groups (Miltner and Zech, 1998, Schoning et al, 2005). Variations in temperature and humidity can cause temporal changes in soil aggregation, which can affect soil microbial activity, arrangement of the soil particles, an increase in the isolation of organic carbon within the aggregates, changes in expansion and contraction cycles and stability of aggregates (Franzluebberrs et al, 2001). Su et al., 2004 found out that even short-term cultivation had a significant influence on soil C, N and soil biological properties, with lower basal soil respiration and enzyme activities than the native grasslands soils.

Depletion of SOC by conversion of primary FO into cropland is the second largest C source of human-induced emissions (Don et al., 2011). The magnitude of SOC depletion in soils of tropical agro ecosystems may be as much as 75 % or more (Lal, 2004). Reduction of SOC below the critical level exacerbates degradation of soil structure, increases bulk density (BD), decreases aggregation, reduces soil moisture storage, decreases aeration (Fageria, 2012), and adversely impacts grain yield (Fuentes *et al.*, 2009). In addition, NT restores soil structure and increases SOC by an average of 0.43 Mg ha-1yr-1at the 0-10 cm depth in tropical soils (Six et al., 2002).Conversion of a conventional tillage system (CT) to NT may increase SOC by 57 ± 14 g m-2yr-1C (West& Post, 2002) and also enhance SOC stabilization and crop yield (Bhattacharyya et al., 2012), improve aggregation, increase soil water reserves (Peres *et al.*, 2010), and reduce the risks of initial compaction under NT by decreasing soil disturbance (Carter et al., 1999).Adoption of NT in conjunction with a complex crop rotation from monoculture can increase SOC by 20± 12 g C m-2yr-1(West & Post, 2002) and it improves soil aggregation by the addition of crop residues on the soil surface or in the soil profile by the root system depending on the crop species and climatic conditions (Martins *et al.,* 2012; Sá *et al*., 2013). (Martins et al., 2012). The LLWR considers the soil moisture range where no limitations to plant growth are expected when considering soil air-filled porosity (AP), resistance to penetration (RP), and plant available water capacity (AWC) between the field capacity (FC) and permanent wilting point (PWP) (Reichert *et al.,* 2009). In addition to the LLWR, other properties may be used to evaluate soil structural quality affected by land use and soil management, such as SOC content (Tivet *et al.,* 2012), SOC stock (Zotarelli *et al.,* 2012), water stable aggregates (WSA) (Martins *et al*., 2012), geometric mean diameter (GMD) (Seben Júnior *et al.,* 2011), RP (Silva & Kay, 2004), tensile strength (TS) (Tormena et al., 2008), total porosity (TP), micro porosity (MI), and macro porosity (MA) (Wendling *et al*., 2012).It is important to evaluate the impacts of intensive management systems on soil structure, such as soil under NT in comparison with soil under FO.

CHAPTER THREE

METHODOLOGY

3.1 Description of the study area

This study was conducted in two agro ecological zones in South Eastern Nigeria; rainforest and derived savannah. In each agro ecological zone, the soil samples were taken in two locations and five different land use systems. The locations in the derived savannah are Nsukka and Neke uno in Enigu State and Umuahia and Umudike (rainforest) in Abia State. The soils of Enugu State are of sedimentary origin (Balogun, 2000) while the soils of Abia State are derived from Coastal Plain Sand. The location under rainforest are denoted by A and B while C and D represent the locations under derived savannah. The five land uses considered are: fallow, forest, excavated, cultivated and grazing land.

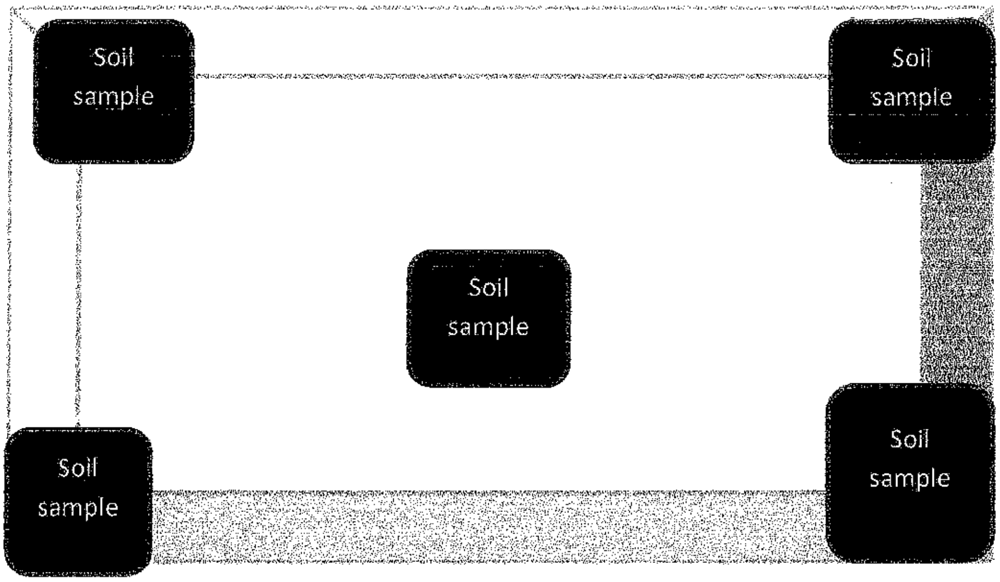
The study area has a tropical wet and dry season lasting from April to October and dry season from November to March. The average annual precipitation in Nsukka is 1600-1800 mm and average temperature of 28^0 C, while the average annual temperature in Umudike is 26^0 C with annual rainfall of 2163 mm. The soils of both agro zones belong to the order Ultisol (Soils Survey Staff, 2010).

Table 1: Description of study locations

Agro zone	Location	Land use	Latitude	Longitude	Elev.(m)	Remark/Common forest trees and
DS	Nsukka	Forest	N06^0.51.393'	E007^0.26.337'	476.4	Native forest:Pentaclethra macrophil
DS	Nsukka	Fallow	N06^0.51.609'	E007^0.26.107'	472.8	12 years
DS	Nsukka	Grazeland	N06^0.51.163'	E007^0.25.520'	476.7	University of Nigeria Nsukka Cattle
DS	Nsukka	Excavated	N06^0.51.138'	E007^0.25.698'	472.4	
DS	Nsukka	Cultivated	N06^0.51.417'	E007^0.26.280'	477.6	Cassava(Manihot esculenta),vegetab
RF	Umudike	Forest	N05^0.28.764'	E007^0.32.266'	119.01	Michael Okpara University Forest re
RF	Umudike	Fallow	N05^0.28.885'	E007^0.32.074'	108.2	Natural fallow >15Years
RF	Umudike	Grazeland	N05^0.28.810'	E007^0.32.303'	108.8	Michael Okpara University Cattle gr
RF	Umudike	Excavated	N05^0.30.556'	E007^0.31.567'	142.82	
RF	Umudike	Cultivated	N05^0.28.906'	E007^0.32.355'	118.9	Cassava *(Manihot esculenta)*, >15y
RF	Umuahia	Forest	N05^0.31.928'	E007^0.28.272'	148.1	Abia State Forest reserve Umuahia:
RF	Umuahia	Fallow	N05^0.32.906'	E007^0.28.360'	125.9	Natural fallow >15years
RF	Umuahia	Grazeland	N05^0.32.528'	E007^0.28.163'	125.9	Community grazing land (Sheep and
RF	Umuahia	Excavated	N05^0.32.879'	E007^0.28.402'	112	
RF	Umuahia	Cultivated	N05^0.28.906'	E007^0.32.355'	125.3	Cassava(Manihot esculenta)andBear
DS	Neke uno	Forest	N06^0.39.908'	E007^0.31.850'	208.4	Native forest:Pentaclethra macrophil
DS	Neke uno	Fallow	N06^0.38.374'	E007^0.32.078'	204.2	Natural fallow >15years
DS	Neke uno	Grazeland				
DS	Neke uno	Excavated	N06^0.37.901'	E007^0.32.824'	193.2	
DS	Neke uno	Cultivated	N06^0.38.404'	E007^0.31.802'	204.2	Cassava(Manihot esculenta),andBea

3.12 Sampling method

The soil samples were collected using the transect method which provides a statistically sound system for soil sampling and observation and it is the simplest of sampling strategies. Transect method involves the use of some paddocks with two distinct soil types which will require a transect line for each soil type. The best way to ensure a representative sample of the field is to traverse the field in a zigzag pattern, collecting samples randomly from the entire field area. The soils samples collected randomly can then be mixed together very well after which the sub sample of the soil should be placed in an appropriate, properly labeled container.



3.2 LABORATORY ANALYSIS

3.21 Physical analysis

Particle size distribution of less than 2 mm fine earth fraction, was measured by the hydrometer method using calgon as the dispersion agent described by Gee and Bauder (1986) with deionized water alone for the determination of water dispersible clay and silt.

Calculations

$$\%\text{silt} + \text{clay} = \frac{40secs\ reading + (0.3 \times b)}{weight\ of\ sample(50g)} \times 100$$

Note: b is the temperature difference between that of the soil suspension and 20°C

$$\%\text{clay} = \%\text{clay} = \frac{2\text{–}hrs\ reading \times 100}{weight\ of\ soil}$$

%silt= (silt + clay) - clay

Total sand = 100- (silt + clay)

3.22 Measurement of micro aggregate stability indices

This involves the determination of the amounts of silt and clay in calgon-dispersed and water-dispersed samples using bouyoucos hydrometer method of particle size analysis described by Gee and Bauder (1986). The data obtained was used in the following micro aggregate stability indices;

ASC = [% clay + % silt (calgon)] – [% clay + % silt (water)]

DR= [% silt + clay (H_2O)] / [%silt + clay (calgon)].

WDC = %clay in water

Note: ASC = Aggregated Silt + Clay, DR= Dispersion Ratio, WDC = water dispersible clay.

Aggregate stability

The distribution of water stable aggregates was estimated by the wet sieving technique described in detail by Kemper and Rosenau (1986). Air dried soil sample was sieved to obtain the aggregates by placing the 4 mm sieve on >2 mm sieve, the soil sample between the two sieves was used as the aggregates. To separate the water stable aggregate, four different sieves was used >2 mm, 0.25 mm, 53 micron and <53 micron was pre-soaked for 5mins in water. The sieves and their contents were oscillated vertically, once per second, in water 20 times using 4cm amplitude. Care was taken to ensure that the soil particles on the topmost sieve were always below the water. The resistant aggregates on each sieve were oven dried at 60°C for 24hr and weighed. The mass of <53 micron was obtained by difference between the initial sample weight and the sum of sample weight collected on the >2 mm, 0.25 mm and 53 micron sieve nests.

The percentage ratio of aggregates in each sieve will represent the water stable aggregate of sizes >2.00 mm, 2 mm-0.25 mm, 0.25 mm-0.053 mm, and < 0.053 mm and was computed as follows:

$$WSA = \frac{Mr}{Mt} \times 100$$

Where Mr is mass of resistant oven - dried aggregates (uncorrected for sand) in the size class fraction after wet sieving and Mt is the total mass of the initial material (25 gm).

Aggregate stability was calculated using the formula

$$\% \text{ Aggregate stability} = \frac{\text{wt. of WSA} - \text{wt. of sand}}{\text{wt. of sample} - \text{wt. of sand}} \times 100$$

Where WSA = Water stable aggregates.

The mean weight diameter (MWD), another measure of stability was calculated using the formula

$$\text{MWD} = \sum_{i=1}^{n} W_i X_i$$

Where Wi = weight of aggregate in the ith aggregate size range as fraction of dry weight of sample.

Xi = Mean diameter of any particular size range of aggregates

Separated by sieving

Sand correction

The sand correction was done by dispersing the material collected from each sieve, using a mechanical stirrer and a dispersing agent which is sodium hexa meta phosphate (calgon). After adding calgon, the mixture was left overnight and shaken on a mechanical shaker the following day. The material was then washed back through the same sieve and the soil samples left on the sieve was oven dried and weighed. The weight of soil left on the sieve was used as the weight of sand.

3.22 Chemical analysis

Organic carbon

The soil organic carbon was determined by Walkey and Black wet oxidation method as modified by Nelson and Sommer (1996). 1 gram of air-dried soils was weighed into a 500 ml conical flask, 10 ml of 0.167M $K_2Cr_2O_7$ were added using pipette, 20 ml of concentrated H_2SO_4 were added and the beaker was swirled to mix the suspension. After 30 minuetes, 100 ml distilled water were added after which 7 drops of 1, 10-phenanthrolin monohydrate were added. 0.5M ferrous sulphate solution was used in titration until the colour changed from light brown to green and finally to brisk red as the end point.

Calculations

$$\%\ \text{organic carbon} = \frac{(B-T)\times 0.003\times 1.33\times 100}{weight\ of\ soil}$$

Where,

B= Blank liter value

T= Sample titre value

M= Molarity of Fe $(SO_4)_2 6H_2O$

Wt= Weight of soil samples.

Soil organic carbon in aggregates

The soil organic carbon in aggregate was also determined by Walkley and Black wet oxidation method as modified by Nelson and Sommer (1996). In this case, 1 g of soil was taken from the oven dried aggregates across each sieve i.e >2 mm, 0.25 mm, 0.053 mm and <0.053 mm. The 1 g of oven dried soil was weighed into a 500ml conical flask, 10ml of 0.167M $K_2Cr_2O_7$ was added using pipette, 20 ml of concentrated H_2SO_4 was added and the beaker will be swirled to mix the suspension. After 30minuetes, 100ml distilled water was added after which 7 drops of 1, 10-phenanthrolin monohydrate was added. 0.5M ferrous sulphate solution was used in titration until the colour changes from light brown to green and finally to brisk red as the end point.

3.23 Statistical analysis

The experiment was arranged as 2 * 2 * 5 in three replications. Data collected were analyzed using Genstat Discovery edition software. The numbers represent (2) agro ecological zones and (2) the locations with (5) different land use in Randomized Complete Block Design (RCBD), where the F-values were significant at P=0.05, the means were separated using FLSD.

CHAPTER FOUR

4.0 Results and discussion

The effect of land use on particle size distribution is shown in Table 2. Forest land has the higher sand content then the cultivated land, excavated land, fallow and grazing land having the least as they follow a sequential order. For the clay content result, it was revealed that there is no significant difference between the different land use types. Grazing was reported to have the highest clay content among the land use types. The silt content of the soils across the land use types shows no significance differences from each other with grazing land having the highest silt content and forest land with the lowest.

The effect agro zone on particle size distribution showed that rainforest had the highest sand and clay content while derived savannah was revealed to have the highest silt content (Table 3).

Interaction of agro-ecological zone and land use indicated that there is no significant difference in rainforest zone and derived savannah zone (Table 5). The interaction of location and land use on particle size distribution also shows no significant difference across the locations. The result indicated high proportion of sand and low proportion of silt under all the land use types. Results have revealed that land use did not affect particle size distribution because texture is an inherent property of the soil.

The textural class of soil under cultivated, excavated, fallow, forest and grazing across locations is presented in Table 3. The texture was sandy loam in excavated and grazing of Location A but had changed to loamy sand in cultivated, fallow and forest. As for location B which is under derived savannah, there was no change in texture across the five land use types.

However, the texture was sandy loam in excavated and forest of location C but changed to loamy sand in fallow and grazing while the texture for cultivated was recorded to be sand. As for location D, there was no change in the texture except for excavated which is loamy sand.

Table 2: Effect of Land use on particle size distribution of the soil (g/kg)

LANDUSE	SAND	CLAY	SILT
Cultivated	766.0	114.4	120.0
Excavated	770.0	117.5	113.0
Fallow	759.0	113.5	127.0
Forest	772.0	116.8	111.0
Grazing	734.0	133.0	133.0
LSD (0.05)	83.7	27.2	71.8
Coef of var (CV)	13.4	12.8	72.5

Table 3: Effect of agro zone on particle size distribution of the soil (g/kg)

Agro zone	SAND	CLAY	SILT
Derived savannah	715.0	116.6	169.0
Rainforest	806.0	121.5	73.0
LSD (0.05)	52.9	17.18	45.4
Coef of var (CV)	13.4	12.8	72.5

Table 4: Effect of Location on particle size distribution of the soil (g/kg)

LOCATION	SAND	CLAY	SILT
A	825.4	108.3	66.3
B	603.8	124.9	271.3
C	828.0	108.9	63.1
D	783.7	134.2	82.1
LSD (0.05)	14.75	11.77	18.83
Coef of var (CV)	13.4	12.8	72.5

Table 5: Interaction of Land use and Agro-Ecological Zones on particle size distribution of the soil (g/kg)

Agro-ecological zone	Land use	Sand	Clay	Silt
Rainforest	Cultivated	854.0	96.05	49.0
	Excavated	817.0	117.1	66.0
	Fallow	810.0	124.7	66.0
	Forest	766.0	154.7	79.0
	Grazing	783.	114.7	103.0
Derived-savannah	Cultivated	678.0	132.3	190.0
	Excavated	723.0	118.0	159.0
	Fallow	709.0	102.3	189.0
	Forest	777.0	78.9	144.0
	Grazing	686.0	151.3	162.0
LSD(0.05)		118.4	38.42	101.6
Coef of var (CV)		13.4	12.8	72.5

Table 6. Interaction of Land use and location on textural class of the soil (g/kg)

Location	Land use	Sand	Clay	SiltTex class
A	Cultivated	813.3	112.3	74.4 loamy sand
	Excavated	775.7	138.9	85.3 sandy loam
	Fallow	875.7	723.0	52.0 loamy sand
	Forest	893.3	723.0	34.4 loamy sand
	Grazing	769.1	145.6	85.3 sandy loam
B	Cultivated	542.4	152.3	305.3 sandy loam
	Excavated	670.1	97.1	232.8 sandy loam
	Fallow	541.6	132.3	326.1 sandy loam
	Forest	661.6	85.6	252.8 sandy loam
	Grazing	603.5	157.1	239.5 sandy loam
C	Cultivated	894.9	72.3	32.8 sand
	Excavated	763.5	163.7	72.8 sandy loam
	Fallow	842.4	98.9	58.7 loamy sand
	Forest	782.4	132.3	85.3 sandy loam
	Grazing	856.8	77.1	66.1 loamy sand
	Cultivated	813.3	120.8	65.9 sandy loam

D	Excavated	870.1	70.4	59.5	loamy sand
	Fallow	776.8	150.4	72.8	sandy loam
	Forest	750.1	177.1	72.8	sandy loam
	Grazing	708.3	152.3	139.5	sandy loam
LSD (0.05)		32.99	26.32	42.11	
Coef of var (CV)		13.4	12.8	72.5	

AGGREGATE STABILITY INDICES

The effect of land use on aggregate stability indices are shown in Table 6. The result indicated that there is no significant difference ($P \leq 0.05$) among the land use types which means that land use had no significant difference on ASC, DR and WDC. This result is in agreement with Azuka *et al.,* (2014) who reported non-significant effect of land use on WDC and ASC. However, %AS was found to be higher in grazing, fallow and forest which were not significantly different from each other but significantly higher than excavated and cultivated. For the MWD, no significant difference was observed except for grazing which was significantly higher than other land use types. The high value indicates higher resistance to erosion. Cultivated and excavated was indicated to have lower MWD. This is in agreement with Gupta *et al* 2010 that revealed that MWD have smaller values in the cultivated than fallow soils indicating maximum disturbances through tillage and the lower accumulation as well as protection of SOC in macro-aggregates.

The effect of agro zone on aggregate stability indices are shown in Table 7. The result indicated that there is no significant difference between the two agro zones in their WDC,DR and MWD. However, ASC and %AS in the derived savannah were 29.5% and 11.7% higher when compared to the rainforest respectively. The effect of location on the aggregate stability indices showed a significant difference between the locations (Table 8). The result revealed that location B is 57% higher than location A and C for ASC. Location A was recorded to have the highest value for %AS and MWD.

The interaction between agro-ecological zones and land use, it was noted that in the derived savannah the cultivated recorded the highest value of ASC,MWD and %AS compared to other land uses while in the rainforest, the forest land use exhibited highest values in ASC, MWD and

%AS. This point to the fact that the direction of effect of land use on these aggregate indices is dependent on the agro zone.

The interaction between locations and land use showed varied result in the different locations across the land use types. In location A, under DR, forest and fallow were not significantly different from each other (0.43 and 0.51) but were significantly higher than other land use types which were not significantly different among themselves (Table 10). In location C, values of DR followed the following order: cultivated>excavated>forest>grazing while in location C and D, the order is excavated>forest>grazing>fallow>cultivated and excavated>cultivated>fallow>forest>grazing respectively. The variability observed might be due to differences in texture with other locations. Azuka (2014) recorded that all the indices of micro-aggregate stability were not significantly affected ($P<0.05$) by the interaction of sampling period and cover management practices. In the case of WDC, the interaction of location and land use shows no significant difference ($P\leq0.05$). The MWD indicated that there is a significant difference between the locations. It was revealed that cultivated land had higher MWD among the land use types in location A while grazing was reported to have higher MWD in location B. As for location C&D, forest land was recorded to have higher MWD compared to the other land use types. The different effect of land use on aggregate stability indices observed across agro zones and locations may due to differences in soil properties and soil management in the different locations. Also non-significant effect could be as a result of similar texture indicated in the locations. Higher MWD and %AS is an indicator of soil resistance to erosion by water. High stability and increase in MWD shows an improvement in soil physical properties. High DR is an indicator of soil degradation.

Table 7: Effect of land use on aggregate stability indices

LANDUSE	%ASC	%DR	%WDC	%AS	MWD
Cultivated	15.9	0.37	5.58	56.9	1.05
Excavated	15.4	0.34	4.86	47.9	0.90
Fallow	16.5	0.34	4.32	70.8	1.28
Forest	15.4	0.35	4.50	66.6	1.22
Grazing	18.9	0.30	4.86	70.6	1.50
LSD (0.05)	NS	NS	NS	9.46	0.23
Coef of var (CV)	48.6	26.7	15.8	18.4	23.3

Table 8: Effect of agro zone on aggregate stability indices

LANDUSE	%ASC	%DR	%WDC	%AS	MWD
Derived savannah	19.3	0.35	4.61	66.5	1.24
Rainforest	13.6	0.33	5.04	58.7	1.14
LSD(0.05)	4.15	0.05	0.40	5.98	0.14
Coef of var (CV)	48.6	26.7	15.8	18.4	23.3

Table 9: Effect of location on aggregate stability indices

LOCATION	%ASC	%DR	%WDC	%AS	MWD
A	11.57	0.38	4.32	70.93	1.30
B	26.98	0.33	4.90	61.98	1.19
C	11.59	0.36	5.33	68.12	1.26
D	15.58	0.31	4.75	49.28	1.02
LSD (0.05)	1.56	NS	NS	4.95	0.12
Coef of var (CV)	48.6	26.7	15.8	18.4	23.3

Table 10: Interaction of land use and agro zone on aggregate stability indices

Agro-ecological zone	Land use	%ASC	%DR	%WDC	%AS	MWD
Rainforest	Cultivated	8.5	0.46	5.76	39.0	0.59
	Excavated	12.6	0.35	5.40	45.0	0.79
	Fallow	12.8	0.33	4.32	70.6	1.33
	Forest	17.5	0.26	4.68	75.7	1.57
	Grazing	16.4	0.28	5.04	63.2	1.40
Derived-savannah	Cultivated	23.2	0.29	5.400	74.8	1.51
	Excavated	18.2	0.33	4.320	50.9	1.02
	Fallow	20.2	0.35	4.320	71.1	1.22
	Forest	13.3	0.44	4.320	57.5	0.88
	Grazing	21.5	0.32	4.680	78.0	1.59
LSD(0.05)		9.27	0.11	0.89	13.37	0.32
Coef of var (CV)		48.6	26.7	15.8	18.4	23.3

Table 11: Interaction of land use and location on aggregate stability indices

Location	Land use	%ASC	%DR	%WDC	%AS	MWD
A	Cultivated	12.63	0.32	5.76	83.09	1.89
	Excavated	16.15	0.28	3.60	52.59	0.90
	Fallow	7.39	0.43	3.60	76.08	1.36
	Forest	5.35	0.51	5.04	61.52	0.68
	Grazing	16.33	0.30	3.60	81.39	0.68
B	Cultivated	33.77	0.26	5.04	66.56	1.134
	Excavated	20.33	0.38	5.04	49.17	1.139
	Fallow	32.95	0.28	5.04	66.04	1.096
	Forest	21.23	0.37	3.60	53.57	1.076
	Grazing	26.61	0.33	5.76	74.59	1.485
C	Cultivated	4.47	0.5752	5.76	47.53	0.744
	Excavated	18.33	0.2253	5.04	64.46	1.236
	Fallow	10.44	0.3477	5.04	70.49	1.308
	Forest	15.72	0.2816	5.76	82.30	1.595
	Grazing	9.00	0.38	5.04	75.83	1.395
D	Cultivated	12.63	0.33	5.76	30.40	0.443

	Excavated	6.95	0.47	5.76	25.56	0.334
	Fallow	15.23	0.32	3.60	70.64	1.344
	Forest	19.23	0.23	3.60	69.16	1.545
	Grazing	23.85	0.18	5.04	50.62	1.412
LSD(0.05)		3.484	0.075	0.000	11.07	0.26
Coef of var (CV)		48.6	26.7	15.8	18.4	23.3

Percentage water stable aggregate

No significant difference ($P<0.05$) due to land use was observed except for grazing that was significantly higher than excavated, cultivated, fallow and forest under 4-2mm and 2-0.25mm which agree with other studies that cultivated soils were less stable and have predominantly small aggregates compared with the virgin soils. Excavated has the highest value under <0.25-0.053mm and grazing was recorded to have the highest value under <0.053mm. As many researchers have revealed, farm machinery could disturb the soil aggregate fractions and ultimately affect WSA (Six *et al*). Soil aggregation can be increased with cropland conversion to no-tillage due to the rapid turnover of SOC in the soil layers (Bronick *et al*). The mean result of the different size fractions of water stable aggregates under the different land use types is not significantly different. This result showed that the formation of WSA was improved in forest, fallow and grazing compared to cultivated and excavated, this variation might be the effect of interruption of farmer practices. This is in line with the existing studies (Peng *et al*). This result shows that land use significantly affects WSA and the stability varies with the size fractions. As indicated in the result, macro aggregates (4-2mm & 2-0.25mm) were recorded to have higher values than micro aggregates (0.25-0.053mm& <0.053mm).

The effect of agro zone on %WSA across the different size fraction revealed that more macro aggregates were recorded in the derived savannah compared to the rainforest while higher value of micro aggregate was indicated in the rainforest.

The interaction of agro zone and land use on %WSA also indicated higher values in forest, fallow and grazing under 4-2mm and 2-0.25mm while excavated was reported to have the highest value under 0.25mm-0.053mm.

The interaction of location and land use (Table 15) on WSA shows that there is significant difference among the locations.

In all the locations except location A, it was observed that grazing land showed the highest WSA in 4-2mm sieve fraction.

Cultivated and grazing land was reported to have higher value in location A but changed in the other locations as grazing and forest was reported to have higher value under 4-2mm sieve size.

As for 2-0.25mm, fallow was reported to have higher value in all the locations while excavated was reported to have higher value in location A, B and C compared to other land use types under 0.25-0.053mm.

It can be suggested that higher macro aggregate in the grazing land use may be attributed to the aggregating effect of organic material from animal droppings and straw

Higher percentage macro aggregates improve soil structure which infers high porosity; increase in infiltration rate, low bulk density, air circulation, root penetration and reduction in soil erosion. In contrast, higher level of aggregate in <0.053mm may lead to soil dispersion, clogging of soil pores resulting to run off and soil erosion.

Table 12: Effect of land use on percentage water stable aggregate (g/kg)

LANDUSE	>2mm	2-0.25mm	.25-0.053	<0.053mm
Cultivated	24.4	26.9	17.30	13.4
Excavated	22.5	18.3	23.92	12.7
Fallow	29.0	34.7	13.13	11.4
Forest	31.7	23.1	11.26	11.6
Grazing	41.4	20.7	7.51	16.8
LSD (0.05)	8.80	7.06	5.35	7.10
Coef of var (CV)	36.0	34.7	44.5	65.6

Table 13: Effect of agro zone on percentage water stable aggregate (g/kg)

Agro zone	>2mm	2-0.25mm	.25-0.053	<0.053mm
Derived savannah	30.3	28.1	16.62	10.0
Rainforest	29.2	21.4	12.62	16.3
LSD(0.05)	5.57	4.47	3.381	4.49
Coef of var (CV)	36.0	34.7	44.5	65.6

Table 14: Effect of location on percentage water stable aggregate (g/kg)

LANDUSE	2mm	0.25mm	0.053mm	<0.053mm
A	33.90	24.44	11.04	8.93
B	26.78	31.86	22.21	11.11
C	32.32	24.38	12.66	9.70
D	26.15	18.36	12.58	22.94
LSD(0.05)	3.922	3.796	2.888	1.938
Coef of var (CV)	36.0	34.7	44.5	65.6

Table 15: Interaction of land use and agro zone on percentage water stable aggregate (g/kg)

Agro-ecological zone	Land use	>2mm	2mm-0.25	0.25-0.053	<0.053
Rainforest	Cultivated	10.9	21.8	17.98	20.0
	Excavated	19.1	17.5	19.02	14.0
	Fallow	31.9	31.5	12.46	11.6
	Forest	43.2	23.5	6.99	12.8
	Grazing	41.2	12.5	6.67	23.2
Derived-savannah	Cultivated	37.8	32.0	16.62	6.9
	Excavated	25.9	19.1	28.83	11.4
	Fallow	26.1	38.0	13.80	11.3
	Forest	20.2	22.7	15.52	11.3
	Grazing	41.7	29.0	8.35	10.3
LSD(0.05)		12.45	9.99	7.560	10.04
Coef of var (CV)		36.0	34.7	44.5	65.6

Table 16: Interaction of land use and location on percentage water stable aggregate(g/kg)

Location	Land use	4-2mm	2-0.25mm	0.25- 0.053	<0.053mm
A	Cultivated	55.97	18.02	9.95	4.62
	Excavated	20.76	23.22	18.58	15.61
	Fallow	33.87	29.27	11.49	5.79
	Forest	12.40	26.29	11.55	7.07
	Grazing	46.48	25.40	3.65	11.58
B	Cultivated	19.68	45.97	23.30	9.09
	Excavated	31.01	15.03	39.07	7.14
	Fallow	18.32	46.65	16.11	16.76
	Forest	28.06	46.65	19.50	13.57
	Grazing	36.83	32.55	13.04	9.01
C	Cultivated	15.37	24.15	14.54	19.82
	Excavated	33.59	18.84	19.23	5.33
	Fallow	32.30	29.17	9.09	13.94
	Forest	42.08	28.84	9.05	4.73
	Grazing	38.27	20.90	11.40	4.69

D	Cultivated	6.41	19.52	21.42	20.09
	Excavated	4.52	16.12	18.81	22.65
	Fallow	31.45	33.91	15.82	9.31
	Forest	44.31	18.13	4.93	20.89
	Grazing	44.06	4.13	1.93	41.76
LSD(0.05)		8.770	8.488	6.457	4.333
Coef of var (CV)		36.0	34.7	44.5	65.6

Total organic carbon

Different land-use systems causes variation in the levels of soil organic matter content in the soil. The effect of land use was significant at ($p<0.05$). Land use practices affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations on the rooting zone (Murty *et al.,* 2002). The results of this study revealed that a mean values for soil organic matter were 1.771, 1.648, 1.998, 3.219, 3.127 in cultivated, excavated, fallow, forest and grazing respectively (Table 11). The result showed higher values in forest and grazing. The increase in forest land might be as a result of the litter falls and plant residues on the surface of the soil while the increase in gazing land might be as a result of the animal droppings and animal dungs when the animal are taken to the land to graze which can contribute to the organic matter content of the soil. Many studies have demonstrated that soil organic carbon storage decreases with shift from a natural land use pattern to an artificial land use pattern, and conversely, soil organic carbon storage increases with a shift from an artificial land use pattern to a natural land use pattern (Rabbi , Dalal , et al. 2015).

The excavated land is recorded to have lower organic matter content because the top soil which is rich in organic matter has been removed. The relatively better organic carbon content in the forest soil is attributable to higher biomass input. This indicates that vegetation restoration has implication for improvement of soil nutrients. This result agrees with Funakawa *et al.,* (1997); Gebrelibanos and Mohammed (2013) that the amount of organic matter is normally highest in the forest soil compared to continuously cultivated soil. Litter fall is the major contribution of soil organic matter in the forest ecosystem. Conversion of the natural forest into continuous cultivation had resulted in significant reductions of both the concentration and stock of organic matter. Lobe *et al.,* (2001) reported that the organic matter content in soils decreased rapidly in the first few years they were cultivated.

The effect of agro zone on organic matter recorded higher value in rainforest (2.854) than derived savannah (1.852)

The interaction of land use and agro-ecological zone showed significantly higher soil organic carbon in the forest and grazing compared to other land use types in the Rainforest agro-ecological zone while a non-significant effect was observed among all the five land use types in the Derived savannah. The reason for this contrary result in the derived savannah could be due to lower rainfall, lower biomass accumulation and decomposition. The interaction of land use and location showed that there is no significant difference in location A&B across the different land use types. In the case of location C&D, the result shows no significant difference among the land use types except for forest and grazing which was significantly higher than the other land use types.

Organic carbon in aggregates

The effect of land use on organic carbon in aggregates is presented in Table 16. The result revealed that forest and grazing had the highest organic carbon across all aggregate sizes compared to other land use types.

Considering the Effect of agro zone on organic carbon in aggregates, 53% and 43% higher organic carbon were associated with 2-0.25 and 0.25-0.053in the rainforest respectively compared to the same size fractions in derived savannah. According to the result, macro aggregates (>2mm &0.25mm) sequestered more organic carbon than the micro aggregates (0.053mm).

Allocation of carbon in aggregates in the different locations showed that apart from location A with the highest organic carbon fraction in 4-2mm, location D indicated the highest organic carbon under 2- 0.25mm and 0.25-0.053 though not significantly different with location C for 0.25-0.053mm.

The interaction of location and land use revealed that forest and grazing in almost all locations have the highest organic carbon content across all aggregate sizes. Higher content in grazing land can be as a result of the contribution of the dropping and animal feed to organic carbon level. Soil organic matter is crucial as a precursor to aggregate formation. The increase in forest land might be as a result of the litter falls and plant residues on the surface of the soil which can contribute to increase in organic matter content of the soil.

Table 17: Effect of land use on total soil organic carbon and aggregate fractions (g/kg)

LANDUSE	Total	4-2mm	2mm-0.25	0.25-0.053
Cultivated	10.27	11.3	22.8	19.8
Excavated	9.56	2.9	15.6	11.9
Fallow	11.59	15.5	13.1	15.3
Forest	18.67	58.3	31.1	23.7
Grazing	18.14	28.8	32.9	21.0
LSD(0.05)	33.4	19.32	10.04	5.2
Coef of var (CV)	29.8	92.8	53.0	34.3

Table 18: Effect of location on total soil organic carbon and soil organic carbon in aggregate fraction (g/kg)

Location	Total	4-2mm	2mm-0.25	0.25-0.053
A	10.52	38.12	17.5	13.5
B	10.96	10.04	12.1	13.1
C	12.44	19.98	23.8	23.4
D	20.67	25.27	38.9	23.4
LSD(0.05)	0.43	2.27	5.91	2.3
Coef of var (CV)	29.8	92.8	53.0	34.3

Table 19: Effect of agro zone on total soil organic matter and soil organic matter in aggregate fraction (g/kg)

Agro zone	Total	4-2mm	2mm-0.25	0.25-0.053
Derived savannah	10.74	24.1	14.8	13.3
Rainforest	16.55	22.6	31.4	23.3
LSD(0.05)	2.11	NS	6.35	1.6
Coef of var (CV)	29.8	92.8	53.0	34.3

Table 20: Interaction of land use and agro zone on total soil organic matter and soil organic matter in aggregate fraction (g/kg)

Agro-ecological zone	Land use	Total	>2mm	2mm-0.25	0.25-0.053
Rainforest	Cultivated	8.91	3.9	36.1	26.6
	Excavated	8.55	5.8	22.8	15.9
	Fallow	8.71	9.0	18.6	21.4
	Forest	13.40	8.33	29.7	26.7
	Grazing	14.13	18.4	49.6	26.1
Derived-savannah	Cultivated	11.64	18.6	9.4	13.0
	Excavated	10.57	0.00	8.4	7.9
	Fallow	14.46	22.1	7.7	9.1
	Forest	23.94	33.2	32.4	20.8
	Grazing	22.14	39.2	16.1	15.8
LSD(0.05)		4.72	27.32	14.20	3.6
Coef of var (CV)		29.8	92.8	53.0	34.3

Table 21: Interaction of land use and location on total soil organic matter and soil organic matter in aggregate fraction (g/kg)

Location	Land use	Total	>2mm	2mm-0.25	0.25-0.053
A	Cultivated	9.71	0.00	11.2	16.6
	Excavated	9.91	11.5	3.9	1.4
	Fallow	6.38	7.8	8.5	7.5
	Forest	9.51	14.83	32.4	22.5
	Grazing	17.09	23.0	31.4	19.5
B	Cultivated	8.11	7.8	7.7	9.4
	Excavated	7.18	0.00	12.9	14.3
	Fallow	11.04	10.2	6.9	10.7
	Forest	17.29	18.3	32.4	19.1
	Grazing	11.17	13.8	0.8	12.1
C	Cultivated	9.18	12.6	34.0	31.1
	Excavated	6.78	0.00	8.4	5.5
	Fallow	12.04	20.1	19.2	27.2
	Forest	18.82	27.1	25.0	29.4
	Grazing	15.36	40.1	32.3	24.0

	Cultivated	14.10	24.7	38.2	22.0
D	Excavated	14.36	0.00	37.3	26.3
	Fallow	16.89	24.0	17.9	15.7
	Forest	29.06	39.4	34.4	23.9
	Grazing	28.93	38.3	66.9	29.3
LSD(0.05)		0.95	2.5	13.21	2.5
Coef of var (CV)		29.8	92.8	53.0	34.3

CHAPTER FIVE

Summary and conclusion

In each agro ecological zone, land use did not directly affect the particle size, micro aggregate stability indices in the soils. However, the significant differences observed between the two agro zones could be due to differences in the inherent soil properties. The soil texture was significantly different which could be as a result of differences in the parent material of the locations except for location B which had similar soil texture.

The soils in derived savannah had higher stability than soils in the rainforest zone probably because of the high aluminum and iron oxides found in the soils.

Despite the higher soil organic carbon in the rainforest, the derived savannah exhibited higher aggregate stability which can be linked to iron oxide and aluminum oxide content.

Since the forest and grazing land use systems are superior in terms of improving soil quality, fallow lands can be converted to grazing land while addition of organic material is recommended in the arable lands.

The use of excavated land for agriculture would necessitate some sustainable management practices that would restore the top soil.

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