DEPTH AND TOPOGRAPHIC POSITION EFFECTS ON DISTRIBUTION OF SOIL ORGANIC CARBON IN RELATION TO AGRICULTURAL LAND USE AND MANAGEMENT IN IKOLE-EKITI, EKITI STATE.

By

AKINYEMI BLESSING TITLOPE

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ABSTRACT

Anthropogenic activities can destroy or drastically reduce the organic carbon contents of soils. This study was conducted to evaluate the effects of two land use management practices (arable land and oil palm land), soil depth and topography on soil organic carbon contents. The study was carried out in Ikole-Ekiti, Ekiti State, Nigeria. At each location, three topographic units were identified as upper slope, middle slope and lower slope at 50 m apart. A mini pit of 150 cm by 100 cm by 60 cm in length, breadth and depth, was dug and marked into delineated horizons of 0-20, 20-40 and 40-60 cm depths. The physical and chemical properties of all samples were determined. The data collected were subjected to analysis of variance (ANOVA) using the Randomized Complete Block Design (RCBD). In both agricultural land use types studied, the SOC was not significantly affected by (<0.05) slope levels and soil depths but the lower position recorded higher SOC contents at the surface soil depth (0-20cm). The highest mean SOC contents in the middle slope of both land use types can be due to tillage practices. Conservation tillage practices, crop residue management and addition of manure and compost should be recommended in order to increase and maintain soil organic content in the soils.

Keywords: Soil organic carbon(SOC), soil depth, topography, land use.

CERTIFICATION

This is to attest and certify that this project titled " Depth and topographic position effects on distribution of soil organic carbon in relation to agricultural land use and management in Ikole-Ekiti, Ekiti state'' has met the requirement of a final year student project and the Federal Government Institutional principles and regulations guiding the Award of Bachelor of Agriculture. (B. Agric) degree in Federal University Oye-Ekiti and approved to have contributed to knowledge and has given relevant information as regard the topic in view.

…………………… 28/03/19.

PROF. O. S. SHITTU **Date**

Supervisor

B. Agric Soil Science (Ife)

M.Sc Agronomy (Ibadan)

Ph.D Soil Science (Ilorin)

Professor of Soil fertility and Mineralogy

Head of Department

Soil science and Land Resources Management.

DEDICATION

I dedicate this work to my loving father, brother, and friend, Jesus Christ who is the King of kings and the Lord of lords. All glory and honour be to His Holy name.

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May the good Lord bless them all beyond measure in Jesus name, Amen.

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CHAPTER ONE

1.0 INTRODUCTION

The soil is the solid material on the earth's surface that results from the interaction of weathering and biological activity on the parent material or underlying hard rock. The soil consists solid (mineral and organic), liquid and gaseous phase.

Soil organic carbon (SOC) is one part in the much larger global carbon cycle that involves the cycling of carbon through the soil, vegetation, ocean and the atmosphere. The SOC pool stores estimated 1 500 (Petagram Carbon) PgC in the first meter of soil which is more carbon than is contained in the atmosphere (roughly 800 PgC) and terrestrial vegetation (500 Pg C) combined (FAO and ITPS, 2015). This phenomenal SOC reservoir is not static but is constantly cycling between the different global carbon pools in various molecular forms (Kane, 2015).

Dead organic material (mainly in the form of plant residues and exudates) is incorporated into the soil by soil fauna leading to carbon inputs into the soil through organic material transformation by heterotrophic microorganisms. This organic material transformation process results in a complex biogeochemical mixture of plant litter compounds and microbial decomposition products in various stages of decomposition that can be associated with soil minerals and occluded within aggregates enabling SOC persistence in soil for decades, centuries or even millennia (Schmidt *et al.*, 2011).

Enhancing organic carbon storage below the soil surface ("sub-soil") is an attractive option because in most soils, organic matter content decreases with increasing depth from the surface. Soil organic carbon content is one of the key soil properties associated with many soil functions. It is a source of nutrients and is crucial for agricultural production.

Increases in SOC stock increase crop yields in high-input commercial agriculture but especially in low-input degraded lands. Sustainable soil management that increases SOC stocks should be developed on a local and global basis and should be adopted for more sustainable food systems. SOC age frequently increases with increasing depth and is typically more stable than SOC near the surface (Hobley *et al.* 2014) so that targeting subsurface stocks of SOC may lead to a longer retention of the additional carbon. Identifying the key environmental, site and management factors driving SOC storage and depth distribution are keys to the success of enhanced subsurface SOC storage, enabling us to identify sites with the greatest potential for additional subsurface SOC storage.

The influence of topography can be expected to be either buffered or intensified by different tillage and crop management practices (Bergstrom *et al.*, 2001). Topography affects soil C through erosion and redistribution of fine soil particles and organic matter across landscape and through water redistribution leading to varying leaching, infiltration, and runoff potentials (Creed *et al.*, 2002). Topography is one of the key factors of soil formation and its effects on soil C have been well documented; many researchers reported a strong relationship between terrain attributes and soil C at a field scale (Papiernik *et al.*, 2007). General topographical influences on soil C are likely to differ in magnitude under agricultural systems with different tillage.

Topographic features, such as slope, curvature and catchment area control the rates of redistribution of soil across hill slope locations and have an effect on the amount and quality of soil organic carbon (SOC) that is found across the landscape.

The result of meta- analysis of data from 74 publications indicated decline in soil C stocks after land use changes from pasture to plantation (-10%), native forest to plantation forest (-13%), native forest to cropland (-42%), and pasture to cropland (-59%) but soil C increase after land use changes from native forest to pasture (+8%), cropland to pasture (+19%), cropland to plantation forest (+18%), and cropland to secondary forest (+53%). Guo and Gifford [2002]. The results varied, however, depending on factors such as annual precipitation, plant species and length of study periods.

The implication is that pastures and forests, whether native or plantation, compared to cropland are more efficient in storing C in the soil. In Sweden, it has been calculated that nationwide the 270 (Tertagram Carbon) Tg C stock in agricultural surface soil (0–25 cm) is actually decreasing at a rate of 1 Tg year^{-1}[Andren *et al,*.2008]. The loss of C from agricultural soils on a global scale has generated considerable debate and Lal (2008) noted that the C flux from soil to the atmosphere is estimated at 0.8–1.2 Pg C year^{-1} whereas C flux from soil to the ocean is 0.6 Pg C year^{-1}.

Even though organic C in many agricultural soils is being depleted through various mechanisms (oxidation/mineralization, leaching and erosion), there are measures other than land-use changes that potentially can slow down or reverse this trend. Such measures include: i) diverse crop rotations including; leys and cover crops, ii) organic amendments such as manure or crop residues and iii) tillage modifications such as minimum or no tillage.

Enhancing organic carbon storage below the soil surface ("sub-soil") is an attractive option because in most soils, organic matter content decreases with increasing depth from the surface (e.g., Gaudinski *et al.* 2000, Wynn *et al.* 2004). The C stabilization capacity of the sub-soil (Six *et al.* 2002) is therefore less likely to be exhausted and subsurface soils will therefore have a greater capacity for additional SOC storage. SOC age frequently increases with increasing depth and is typically more stable than SOC near the surface (e.g., Rumpel *et al.* 2002, Rasmussen *et al.* 2005, Eusterhues *et al.* 2007, Hobley *et al.* 2014), so that targeting subsurface stocks of SOC may lead to a longer retention of the additional C. Human influences on SOC dynamics are well documented, particularly for surface soils. In Australia, land use and land-management significantly affect SOC stocks near the surface, but effects are more difficult to detect in sub-soils (Wilson *et al.* 2008, 2011, Luo *et al.* 2010). To date no large-scale study has investigated the drivers of SOC at depth in Australia. However, in a comprehensive investigation of the drivers of SOC storage and vertical distribution in the top 30 cm of soil in eastern Australia, land use was the most important indicator of the vertical distribution of SOC (Hobley *et al.* 2015).

Also the drivers of SOC storage (in 0–30 cm depth) differ from those influencing its vertical distribution (Hobley *et al.* 2015) which led to the hypothesis that surface SOC storage in eastern Australia is controlled predominately by water availability as this limits plant growth and SOC production. SOC production is greatest near the surface, so that the influence of water availability on SOC storage is most noticeable near the surface. In contrast, temperature has a greater influence on microbial activity, which determines SOC turnover throughout the soil profile, thereby controlling SOC loss (and availability for translocation) and influencing the depth distribution of SOC. Compared with native sites, anthropogenic land use limits the production of SOC (via removal of plant and animal biomass), and in the case of tillage, leads to a mixing/redistribution of SOC in the tillage layer, which results in a very strong influence of land use on SOC depth distribution.

GENERAL OBJECTIVE

The general objective of this study is to is to access the depth-wise distribution of soil organic carbon in two agricultural land use types in relation to the position on the slope.

SPECIFIC OBJECTIVES

The specific objectives are to:

I. evaluate the topographical and depth wise content and distribution of SOC in arable and tree crop plantation agricultural land use types

II. compare and establish the agricultural land use type and management with potential SOC sustainability

III. establish the relationships between the SOC contents and depth, toposequence and some soil properties

IV. assess the extent of soil heterogeneity due to agricultural land use types and management.

JUSTIFICATION

SOC is a pointer to soil quality in terms of soil nutrient fertility, health, productivity status and environmental quality (Lorenz and Lal, 2005; Bescansa*et al.*, 2006; Singh and Ryan, 2015).

Nonetheless, the SOC status and distribution in the derived savanna soils of Ekiti State has not been evaluated in relation to agricultural land use types and toposequence

CHAPTER TWO

2.0 LITRATURE REVIEW

2.1. SOIL ORGANIC CARBON

In principle, the amount of SOC stored in a given soil is dependent on the equilibrium between the amount of C entering the soil and the amount of C leaving the soil as carbon-based respiration gases resulting from microbial mineralization and, to a lesser extent, leaching from the soil. Locally, C can also be lost or gained through soil erosion or deposition, leading to the redistribution of soil C at local, landscape and regional scales. Levels of SOC storage are therefore mainly controlled by managing the amount and type of organic residues that enter the soil (i.e. the input of organic C to the soil system) and minimizing the soil C losses (FAO and ITPS, 2015).

Factors controlling the decomposition of organic matter in soil include soil temperature and water content (mainly determined by climatic conditions) which greatly influence soil C storage through their effect on microbial activity. The composition of the microbial community (e.g. the bacteria: fungi ratio) may also have an influence on the preferential decomposition of certain compounds. The presumed chemical recalcitrance of complex molecules that build up SOC, such as lignin or lipids, does not substantially contribute to SOM persistence in soil (Marschner *et al.,* 2008; Thévenot *et al.*, 2010). SOM persistence is rather affected by SOC stabilization in the soil matrix through its interaction and association with soil minerals (Schmidt *et al.*, 2011).

Soils that are depleted of SOC have the greatest potential to gain carbon, but also have the least propensity to do so. Since the majority of soils around the world are far from their saturation thresholds, there is great potential for increased carbon inputs and management that protects existing stocks to maximize soil carbon sequestration (Kane, 2015).

Organic matter improves soil aggregate and structural stability which, together with porosity, are important for soil aeration and the infiltration of water into soil. While plant growth and surface mulches can help protect the soil surface, a stable, well-aggregated soil structure that resists surface sealing and continues to infiltrate water during intense rainfall events will decrease the potential for downstream flooding. Porosity determines the capacity of the soil to retain water and controls transmission of water through the soil (FAO and ITPS, 2015). The water stored in soil serves as the source for 90 percent of the world's agricultural production and represents about 65 percent of global fresh water (Amundson *et al.*, 2015). Temperature and precipitation are the most significant factors controlling SOC contents in the soil (Deb *et al.*, 2015). Although increasing temperatures may increase plant production thereby increasing carbon inputs to the soil, it will also tend to increase microbial decomposition of SOC (Keestrea *et al.*, 2016). SOC may reflect previous management regimes and practices rather than current ones (Wilson and Lonergan, 2013). As such, a better understanding of sub-soil OC contents may enable us to decipher the influence of environmental and anthropogenic drivers on the global C cycle, and how this is reflected in soils and ecosystems.

2.1.1. EFFECT OF DEPTH ON SOIL ORGANIC CARBON

As with Guo *et al.* (2006), Syswerda *et al.* (2011), Corr *et al.* (1999), and others, this study found that SOC density decreased with depth from the surface. The variation of SOC content tended to increase with increasing depth. Kern (1994) attributed the higher variability of SOC content below 30 cm depth to fewer samples having been taken at greater depths. In this study, distribution data indicated that only 25% of horizon samples came from the 120-200 cm range, even though that range accounts for 40% of the total sampling depth. The smaller number of subsoil samples may be related to shallow soil formation due to the presence of parent material or bedrock before 200 cm. It could also be due to a larger average size of subsoil horizons, due to a decrease in differentiating factors.

Olson et al. (2011, 2012), in studies on adjacent sites with similar slope profiles and similar soil series in northern Illinois, found that cropped land had 13-48% lower SOC densities than forested land after 150 years of mostly row crop production. In an analysis of existing data, Mann (1985) found that cultivated loess-derived soils had an average of 40% less carbon in the top 15 cm than non-cultivated ones; specifically, cultivated Udalfs had 28% lower carbon levels than non-cultivated Udalfs. However, Davidson and Ackerman (1993), among others, have determined that most soil C loss following cultivation occurs within the first few years. Although the initial losses from cultivation may have been equal, the SOC gains following establishment of permanent cover may have been higher at the forest sites. The forest sites were converted from cultivation to permanent cover at an earlier date than the grass sites were. This means they had a time advantage in accumulating SOC. Corre *et al.* (1999) found that SOC was higher under forest than C3 grass when the forest was at least 60 years old, but lower when the forest was about 30 years old. Forest cover possibly allows for a higher equilibrium level of SOC, which means a longer period of time since cultivation may result in higher levels. As discussed above, the amount and nature of the organic matter inputs under forest also appear to favor greater SOC accumulation. The pedosphere is a 1 to 2-meter-deep layer that supports all terrestrial biotic activity and interacts with the atmosphere, lithosphere, biosphere, and hydrosphere. These interactions influence the biogeochemical cycling of nutrients and water, as well as gas and energy exchanges between soil and atmosphere (Lal *et al.*, 1997). The soil serves as a medium for the accumulation of carbon initially captured by terrestrial biota, the transformation of carbon containing compounds, and the outflow of carbon-containing greenhouse gases into the atmosphere (Konyushkov, 1997). When residues are decomposed in the soil, four basic reactions occur: (1) carbon leaves the soil as CO2 to enter the atmosphere; (2) associated nutrient elements are mineralized; (3) a portion of the carbon is incorporated into microbial biomass; and (4) the remaining fraction of the carbon resides in stable humus. Concurrently, a fraction of humus may be mineralized (Stevenson, 1994).

Chemically, all organic material in the soil can be divided into two classes of substances: (1) the various organic compounds that belong to well-known groups in organic chemistry such as proteins, carbohydrates, and organic acids (10 to 15% of soil organic matter), and (2) a second class of compounds, making up about 85-90% of soil organic matter, are not related to any recognized groups in organic chemistry, and are termed humus (Kononova, 1966). Soil organic matter contains about 58% organic carbon, though this range is highly variable (Soil Survey Staff, 2004). Soil organic matter can be conceptualized as pools of material that differ in their susceptibility to microbial decomposition. Agronomically, organic matter is divided into so called active and stable pools. The active pool includes surface litter, particulate organic matter (POM), microbial biomass, and non humic substances not bound by mineral particles (Stevenson, 1994).

2.1.2. EFFECT OF TOPOGRAPHY ON SOIL ORGANIC CARBON

SOC densities were significantly higher in down slope positions (foot slopes and toe slopes) than in upslope positions (summits, shoulders, and back slopes). These differences may be attributable to the effects of topography on moisture content, depth of soil formation, and erosion and deposition. First, the topography affects how much water flows to the different positions on the landscape. Yeakley *et al.* (1998) found that upslope positions had lower soil moisture during both drought and recharge conditions. Soils at the foot slope and toe slope positions receive water from upslope positions via both run-off and through-flow.

The balance between plant organic matter production, decomposition of organic materials, and humus formation at each slope position may have been influenced by relative moisture contents. Based on water inputs, plant growth may have been greater at down slope, positions, which may have translated into higher inputs of fresh organic matter to the soil each year. Decomposition rates of organic matter were found to generally increase with higher soil moisture content (Sequaris *et al.*, 2010), although aerobic decomposition would be suppressed during times of saturation (Swift *et al.*, 1979). Aerobic decomposition is generally highest at a soil water potential near -50 kPa (slightly drier than field capacity, -33 kPa in loam and clay loam soils), with decreased activity at water contents wetter or drier than this water potential value (Voroney, 2007). Readily-decomposed organic matter may have been more quickly decomposed at lower slope positions if moisture levels were closer to ideal. However, the rates of humus formation at upslope versus down slope positions may be more important than the decomposition rates of fresh organic matter. The microbial communities at upslope and down slope positions may be different. Fungi are more tolerant of dry soil conditions than bacteria (Voroney, 2007), so they may be more prevalent at upslope positions. Although some bacteria and actinomycetes can degrade lignin, fungi are the most successful and efficient at lignin decomposition (Horwath, 2007). Partial, rather than complete degradation of lignin at the down slope positions may have led to greater levels of humus formation.

Upslope soils may have lower SOC than down slope soils because of the effect of topography on the depth of soil formation. The depth to the zone of clay accumulation has been shown to decrease with increasing slope gradient on loess landscapes. Soils at the shoulder and slope positions, where gradients are highest, should then have the lowest SOC densities deep in the profile, while summits, foot slopes, and toe slopes should be higher. That is indeed the pattern seen in the SOC by standard depth interval data; median densities were lowest for shoulders and back slopes from 30-60 and 60-100 cm. Summits were slightly higher at those depths. Foot slope and toe slope soils had the highest SOC densities at all intervals between 15-200 cm. Humus molecules may form organo-mineral complexes with clay particles. Since much of the SOC in the down slope positions is deep in the subsoil where clay content is high, this clay-SOC association may be protecting the organic matter from decomposition.

SOC differences between slope positions may also be caused by erosion and deposition. Soil erosion affects SOC content in two ways: by redistributing the surface soil, which is highest in C, and by degrading the soil's productivity at the erosion sites. Vanden Bygaart (2001) found that topsoil had been eroded from upslope positions, primarily from the shoulder, and deposited in down slope positions, mainly the foot slope. Erosion that occurred prior to human disturbance likely would have followed this same pattern. Higher organic matter levels at foot slope and toe slope positions lead to higher fertility, due to effects such as higher cation exchange capacity, increased water-holding capacity, lower bulk-density, and nutrient mineralization. The physical relocation of SOC from eroded positions to depositional positions, along with increased organic matter generation due to higher plant production, likely had a role in higher SOC contents found at the foot slopes and toe slopes.

Considering that the effect of topography can manifest in both the quantity and quality of SOC along hill slopes, it is evident that restoration efforts, land management, and other interventions aimed at conserving and protecting the land will largely depend on our understanding of the relationship between topographic features and SOC contents. However, despite the relevance and large interest surrounding this topic, the relationship between landscape scale erosion and deposition and SOC dynamics still has to be clearly described (Berhe *et al.*, 2008), and much remains unresolved about how SOC quantity and quality can vary among landscapes with differing topography and disturbance histories. The balance between plant organic matter production, decomposition of organic materials, and humus formation at each slope position may have been influenced by relative moisture contents. Based on water inputs, plant growth may have been greater at down slope, positions, which may have translated into higher inputs of fresh organic matter to the soil each year.

2.1.3. EFFECTS OF AGRICULTURAL LAND USE ON SOIL

Agriculture is not only the back bone of the economy but also the major occupation for nearly 85% of the population. Furthermore, long-term economic development and poverty alleviation programs in Ethiopia are based on the development in agricultural economy (Anonymous, 2002). Survival and wellbeing of communities that are dependent on subsistence agriculture and centuries old farming practices such as Ethiopia depend on the extent of maintaining soil fertility and other soil quality parameters (Heluf and Wakene, 2006).

Soil organic C (SOC) and total N (TN) contents play a crucial role in sustaining soil quality, crop production, and environmental quality due to their effects on soil physical, chemical, and biological properties. The type of land use system is an important factor that controls soil organic matter levels since it affects the amount and quality of litter input, the litter decomposition rates and the processes of organic matter stabilization in soils (Römkens*et al.*, Abera and Belachew, 2001). The rapidly increasing population pressure on the highlands of Ethiopia has led to vast changes in land use pattern mainly caused by increasing agricultural production. In this region, cultivated lands showed slow but continuously increasing trend at the expense of forest and grasslands over the last four decades (Getu, 2000; Kebrom and Dedlund, 2000; Selamyihum and Tekalign, 2003; Zewdu*et al.*, 2004).

Soil organic carbon was significantly affected by the type of land use systems. In all soil depth, except 30-60 cm, organic carbon is lower in cultivated fields as compared to other land uses. For instance, the analysis of surface sample (0-5 cm) at Sinana Dinsho showed that the highest SOC (12.95%) was recorded from soils under virgin forest and the least SOC (2.75%) was in cultivated soil. Similarly, the highest SOC (7.58%) was recorded in soils under grassland followed by fallow lands (4.09%) and the least in cultivated soils (2.56%) at Gassera district in similar depth. Most cultivated soils of Ethiopia are poor in organic matter contents due to low amount of organic materials applied to the soil and complete removal of the biomass from the field (Yihenew, 2002), and due to severe deforestation, steep relief condition, intensive cultivation and excessive erosion hazards.

The lowest soil organic carbon in cultivated fields could be due to low organic matter inputs coupled by reduced physical protection of SOC as a result of tillage and increased oxidation of soil organic matter. This was in agreement with John *et al.* (2005) who reported an increasing SOC concentration in the A horizon in the order arable soils < grassland soil <forest soil. The result of the present study is also in conformity with the findings of many other authors (Dawit*et al.*, 2002; Celik, 2003; Merino *et al.*, 2004; Heluf and Wakene, 2006; Gebeyaw, 2007) elsewhere.

The SOC of virgin forestlands were higher than the virgin grasslands most probably because of differences in management practices between the two-land use systems. Soils of the forest sites were well protected (under National park at Sinana-Dinsho), with little disturbance but that of the virgin grassland were poorly managed; heavily overgrazed, and mostly they were susceptible to surface erosion and water logging. In addition to this cow dung is largely used as fuel source rather than enriching SOC of grassland sites.

Irrespective of the land use considered, there were decreasing trends of SOC contents with increasing soil depth, implying that the surface soil layer is the most biologically active part of the soil profile. However, the decrease of SOC was gradual in cultivated and fallow lands as compared to virgin forestland, may be due to disturbances by tillage implements, which could mix different soil layers. The OC concentration under corn was similar for soil layers within the plow layer, ranging between 19 and 21 g/kg of soil. This finding also corroborates the reports of various workers (Grunzweig*et al.*, 2004; Lal and Puget, 2005; Malo*et al.*, 2005; Heluf and Wakene, 2006).

2.1.4. IMPORTANCE OF SOIL ORGANIC CARBON

Soil organic matter plays an important role in the global C cycle and also serves as an index of soil quality and crop productivity. Thus soil C management is a key component of global climate change studies and sustainable agriculture programs. The net C content in a soil system is a trade off between C additions through plant and microbial biomass inputs and C losses through soil respiration and erosion. In agricultural soils, the type and characteristics of implemented management systems have a substantial influence on soil organic matter. However, even within the same management system, soil C sequestration potentials vary in response to many other factors, including but not limited to topography, parent materials, and microclimatic conditions. Success in promoting soil C sequestration depends on a thorough understanding of various factors controlling soil C and of the interactions among these factors. On a scale of a typical agricultural field, topography, soil disturbance by tillage, and amounts of plant residue returned to soil can be regarded as the main factors affecting spatial variations in soil C.

2.1.5. FACTORS THAT REDUCE SOC LEVEL IN THE SOIL

Soil erosion, transport and deposition by water and tillage drastically affect the distribution of soil organic carbon (SOC) within a landscape (Ritchie and McCarty, 2003; Zhang et al., 2006). Furthermore, soil redistribution is assumed to have a large impact on the exchange of carbon (C) between the pedosphere and the atmosphere, through its influence on both input rates of C to the soil and changes in decomposition of SOC (Lal, 2003; Smith et al., 2005; Liu et al., 2003; Van Oost et al., 2007; Yoo et al., 2005). Three key mechanisms could be identified, which can alter the flux of C between the soil and the atmosphere: (i) Dynamic replacement: at eroding sites, the depleted SOC pool can, at least partially, be replaced by newly assimilated C. Continued C input and a decrease in SOC available to decomposition can lead to a net gain of C at these sites. (ii) Burial of topsoil SOC and reduced decomposition: as suggested by Stallard (1998), the rate of decomposition of SOC in depositional settings can be reduced due to a combination of physical and chemical processes, such as increased soil wetness, limited aeration, compaction and physical protection of the deposited soil material within newly formed aggregates (De Gryze *et al.*, 2007). Effect of soil redistribution on soil organic carbon leading to a preservation of buried C. (iii) Transport and increased decomposition: the disruptive energy of forces applied to the soil by water erosion (raindrop impact, the shearing force of flowing water and collision with other aggregates), may cause the breakdown of aggregates (Lal, 2003). This process of disaggregation exposes previously protected SOC to microbial decomposition and combined with a relatively greater proportion of labile SOC within larger soil aggregates (Six et al., 2000) could lead to rapid mineralization of this easily decomposable C following water erosion.

It must also be noted that part of the eroded SOC is transported to distal environments and fluvial systems. Its fate, however, is still largely unclear though recent research suggests that even old SOC may become mineralized when transported in water (Cole and Caraco, 2001).

Concerning the relative importance of the above mentioned key mechanisms there is, however, significant scientific disagreement. Together with a lack of process knowledge, opposing assumptions hamper an accurate estimation of the impact of soil redistribution on the terrestrial carbon balance (Berhe et al., 2007). Notwithstanding this ongoing debate, it is generally agreed that the soil system potentially plays a major role in controlling atmospheric carbon dioxide concentrations (Amundson, 2001). Globally, the soil reservoir stores approximately 2344 PgC in the top 3m (1502 PgC in the first meter) (Jobbagy and Jackson, 2000).

Even a small additional relative flux to/from this system as a result of increased storage/respiration of SOC through soil erosion, could substantially affect soil carbon storage and atmospheric CO2 concentrations. Attempts to globally assess this effect by linking carbon dynamics to soil erosion and deposition patterns resulted in the assertion of a net sink of 1.0 PgC yr−1 (Smith et al., 2005) up to 1.5 PgC yr−1 (Stallard, 1998) as well as a net source of 1.1 PgC yr−1 (Lal, 2003). More recently, and based on an integrated study of the different, simultaneously occurring processes and their interactions, an erosion-induced sink of 0.12 PgC yr−1 on global agricultural land was proposed (Van Oost et al., 2007).

One of the major uncertainties concerns the fraction of SOC that is mineralized when soil is eroded by water, from the moment when detachment takes place until the moment when the SOC becomes protected due to burial (Lal, 2003). Based on the distribution of soil organic matter components along an eroded soil catena, Beyer *et al.* (1993) estimated 70% of the non-humin fraction of soil C in colluvial material to be decomposed during translocation or shortly after deposition. Jacinthe et al. (2001) compared SOC inventories and quality of SOC on cropland and adjacent depositional zones. The pools of labile C in the deposits (on average 9% of total SOC) were 20 to 46% lower than expected. The latter could be interpreted as the result of mineralization of labile C pools during transport and deposition. When combining inventories of SOC and erosion tracers from a wide range of agricultural soils to derive evidence for erosion-induced carbon dynamics, Van Oost *et al.* (2007) concluded that losses of C associated with transport are relatively minor and that most deposited C is effectively preserved. The few experimental studies, in which estimates of eroded C mineralization are supported by direct quantitative data, neither succeed to provide a unique answer. Jacinthe *et al.* (2002) measured the CO2-efflux from incubated samples of runoff, generated during simulated rainfall events on different small soil blocks. Despite large differences in sediment delivery rate and initial soil C content, a consistent 31 to 37% of total eroded C was found to be potentially mineralizable. Polyakov and Lal (2004) subjected five soil plots, positioned at different slopes and connected in a cascade fashion, to simulated rainfall.

Agricultural practices are one of the major factors that affect soil organic matter dynamics by altering above and below ground organic matter inputs and decomposition rates. Soil texture plays an important role in influencing the amounts and turnover rates of Soil Organic Carbon (SOC) as well. However, few studies have investigated the interaction between these two major factors of influence on SOC.

Changes in soil organic carbon (SOC) stocks significantly influence the atmospheric C concentration. Agricultural management practices that increase SOC stocks thus may have profound effects on climate mitigation. Additional benefits include higher soil fertility since increased SOC stocks improve the physical and biological properties of the soil. Intensification of agriculture and land-use change from grasslands to croplands are generally known to deplete SOC stocks. The depletion is exacerbated through agricultural practices with low return of organic material and various mechanisms, such as oxidation/mineralization, leaching and erosion. However, a systematic review comparing the efficacy of different agricultural management practices to increase SOC stocks has not yet been produced.

2.1.6. MANAGEMENT PRACTICES THAT IMPROVE SOIL ORGANIC CARBON

Maintaining or improving soil health is essential for sustainable and productive agriculture. 'Healthy' soil will help to push sustainable agricultural productivity close to the limits set by soil type and climate. Key aspects of 'healthy' soil include the following:

- A comprehensive soil covers of vegetation.
- Soil carbon levels close to the limits set by soil type and climate.

- Minimal loss of soil nutrients from the soil through leaching.
- Zero or minimal rates of rainfall run-off and soil erosion.
- No accumulation of contaminants in the soil.
- Agriculture, which does not rely excessively on fossil energy through inorganic fertilizers.

In many regions of the world, health is severely threatened by human and livestock population increases. This has resulted in the intensification of soil cultivation in existing high potential areas, the expansion of farming into forests and marginal environments with fragile soils, and the over stocking and overgrazing of natural pastures. Combined with the constraints that small-scale farmers face with regard to the availability and cost of organic and inorganic nutrient inputs, these factors have resulted in the wide scale decline of soil health and, hence, productivity in such regions.

- **Productivity:** All interventions that improve soil fertility, soil water availability and reduce the loss of nutrient-rich topsoil through erosion, will straightforwardly improve productivity.
- **Adaptation:** In many parts of the world, intense rainfall events are already a common occurrence and result in a high risk of rainfall run-off and soil erosion, especially on sloping land. Climate change projections suggest that the frequency and severity of such events are very likely to increase. There is a wide range of soil management interventions, which help reduce the risk of run-off and soil erosion, ranging from field or farm level interventions such as contour ploughing or contour tillage with tied ridges, micro-catchments and surface mulching, to landscape level approaches such as land terracing, contour stone bunds or reforestation.

- **Mitigation:** Soil management can help mitigate climate change as well through a range of interventions (Smith et al. 2007). Soils are an important below ground 'sink' for carbon sequestration, and soil management interventions can help to harness this characteristic. For example, the organic matter additions recommended in Conservation Agriculture (Richards et al. 2014, and see case study below), the inclusion of trees in crop fields, and the improved grazing management of natural pastures are all practices that help to increase the sequestration of carbon. The emission of the greenhouse gas (GHG) nitrous oxide from inorganic fertilizer use can also be reduced through integrated approaches to the management of nitrogen fertilizer. For example, Integrated Soil Fertility Management (Fairhurst 2012; Roobroeck et al. 2015. See also case study below.) advocates reduced amounts and more strategically placed inorganic nitrogen fertilizer. Rice lowlands with submergence are known to maintain much higher soil C then lowlands which go through wetting and drying cycles used in rice-wheat cultivation or uplands with maize-wheat rotations (Ladha et al. 2011).
- Conservation Agriculture (CA) was introduced in the 1930s as a soil conservation system to counter the Dust Bowl in the United States. More recently, it has become widely promoted and adopted in Latin America. In Africa, however, adoption rates by small-scale farmers has been slower and more context specific (FAO 2009). CA is based on three principles (Richards et al. 2014):
- **Minimum soil disturbance:** Zero tillage is ideal, but the system may involve controlled tillage in which no more than 20 to 25% of the soil surface is disturbed.
- **Retention of crop residues or other soil surface cover:** Many definitions of CA use 30% permanent organic soil cover as the minimum, but the ideal level of soil cover is site-specific.

- **Use of crop rotations:** Crop rotation, ideally with legumes, helps reduce build-up of weeds, pests and diseases. Where farmers do not have enough land to rotate crops, intercropping can be used.
- The choice of tillage system allows farmers to optimise the soil environment for crop plants and achieve important environmental benefits. The adoption of conservation tillage methods such as minimum cultivation and residue incorporation can reduce carbon emissions and enhance soil structural stability, thus reducing erosion risk (Zuazo and Pleguezuelo, 2008).
- Only by understanding the complexity of organic matter transformations under contrasting tillage can the full environmental and agronomic benefit be determined. The potential negative effects of conventional or inversion tillage (ploughing) in arable cropping systems, such as the loss of organic matter and structure degradation, can be countered by the use of conservation tillage practices to improve soil quality (Scopeletal.,2005;Lal, 2008;Heetal.,2009). The combined effect of non-inversion tillage and straw incorporation on the accumulation of soil organic carbon was reported to be greater than the effect of either tillage reduction or straw incorporation alone (Kushwaha et al., 2001). West and Post (2002) analyzed data from long term studies across the world and reported an average C gain of 0.57 Mg C ha−1yr−1following a change from inversion
- Tillage to no-tillage systems. No-tillage systems not only conserve soil organic matter, but can reduce greenhouse gas emissions (Smith et al., 1998).
- Observed changes in other biological quality indicators due to straw incorporation following adoption of no-till systems include enhanced microbial activity and biomass (Montemurro et al., 2007). In general, microbial biomass and microbial processes in the surface soil under reduced tillage are significantly greater than those in ploughed soils.

- Hot water extractable carbohydrate and water extractable carbon, being a highly labile component of soil organic matter, are sensitive to soil management practices (Doran and Parkins, 1994) and therefore can be used as a sensitive indicator of soil quality. Phosphatase, glucosidase and urease activity in soil are most frequently used among the specific biochemical soil quality parameters and appropriately, represents the C, N and P cycles (Gil-Sotres et al., 2005).
- Long term field experiments represent a valuable source of information on the impact of agronomy on the carbon sequestration, turnover of soil organic matter, and change in soil quality indicators over time (Benbi and Brar, 2009).

Crop residues on the soil surface in NT generally decompose slower than residues incorporated in soil via tillage because of less contact with microorganisms and differences in soil microclimate (Reicosky et al., 1997). In NT, presence of previous crop residues has been reported to decrease topsoil temperature by 0 to 3°C, increase soil moisture content, and reduce soil aeration (Coote and Malcolm- McGovern, 1989). Based on Rothemsted C model, Balesdent et al. (2000) estimated that for every 2°C decrease in soil temperature the decay rates decrease by a factor of 0.8.

Differences among management systems in terms of plant residue inputs may further affect magnitudes of topographical and tillage effects. Organic based systems with winter cover crops enhance soil C by increasing the amount and diversity of biomass returned to the soil and by increasing the time during which the land is covered by growing plants (Follett, 2001; Teasdale et al., 2007). Benefits of growing winter annual cover crops include increased soil aggregate stability and increased soil N content (McVay et al., 1989; Blevins et al., 1990). However, the beneficial effects of cover crops may differ across the landscape reflecting cover crop growth and performance variability.

Though a substantial number of studies have addressed the relationships between topography and soil C and N and the tillage effects on soil C and N separately, there is less quantitative information on interactions between them. Tillage induced soil losses result in truncated soil profiles in convex slope positions and inverted soil profiles with subsoil material deposited over original surface horizons at convex slope positions (Kosmas et al., 2001; Heckrath et al.,2005; Papiernik et al., 2007). Differences in strength of relationship between topography and soil C under different land use systems were reported by Tan et al. (2004) under cropland, grassland, and forestland in Ohio. In NT, Vanden Bygaart et al. (2002) observed that after adoption of NT, soil C content increased in upper and middle slope positions more than that of lower slope positions. Bergstrom et al. (2001) mentioned that NT had more soil C than conventional tillage only at well-drained upper slope positions.

The ability of agricultural fields to sequester carbon (capture and storage of carbon that would otherwise be lost to the environment) depends on several factors including climate, soil type, type of crop or vegetation cover, and management practices. Employing farming practices that reduce disturbance of the soil (less aeration from tillage helps protect carbon), combined with practices that bring additional carbon to the soil, will allow for carbon sequestration over time. Such practices include implementation of conservation tillage (no-till, zone-till, minimum-till, shallow mixing or injection for manure applications), retaining crop residues, including cover crops in crop rotations, adding organic nutrient sources such as manure and compost, and including perennial crops in crop rotations. Their implementation may slow or even reverse the loss of carbon from agricultural fields, improve nutrient cycling and reduce nutrient loss.

On-farm decision making and farming practices are largely driven by the available markets and the operation's business model (Antwi-Agyei*et al.*, 2015). For example, farmers perceive that due to their long term pre-established links to specific markets, finding new markets for new crop or new hybrids or varieties that sequester more carbon in the soil is a difficult task, as it is unlikely that a farmer would switch crops or intercrop unless there was a guaranteed market (Takahashi *et al.*, 2016). A lack of readily available markets, however, can also include poor physical infrastructure development such as road networks or the absence of appropriate storage facilities for certain crops. This particularly discourages adoption as it weakens the bargaining power of many small-scale farmers who cannot store their harvest on their farms if they choose to do so when market prices are low (Antwi-Agyei*et al.*, 2015).

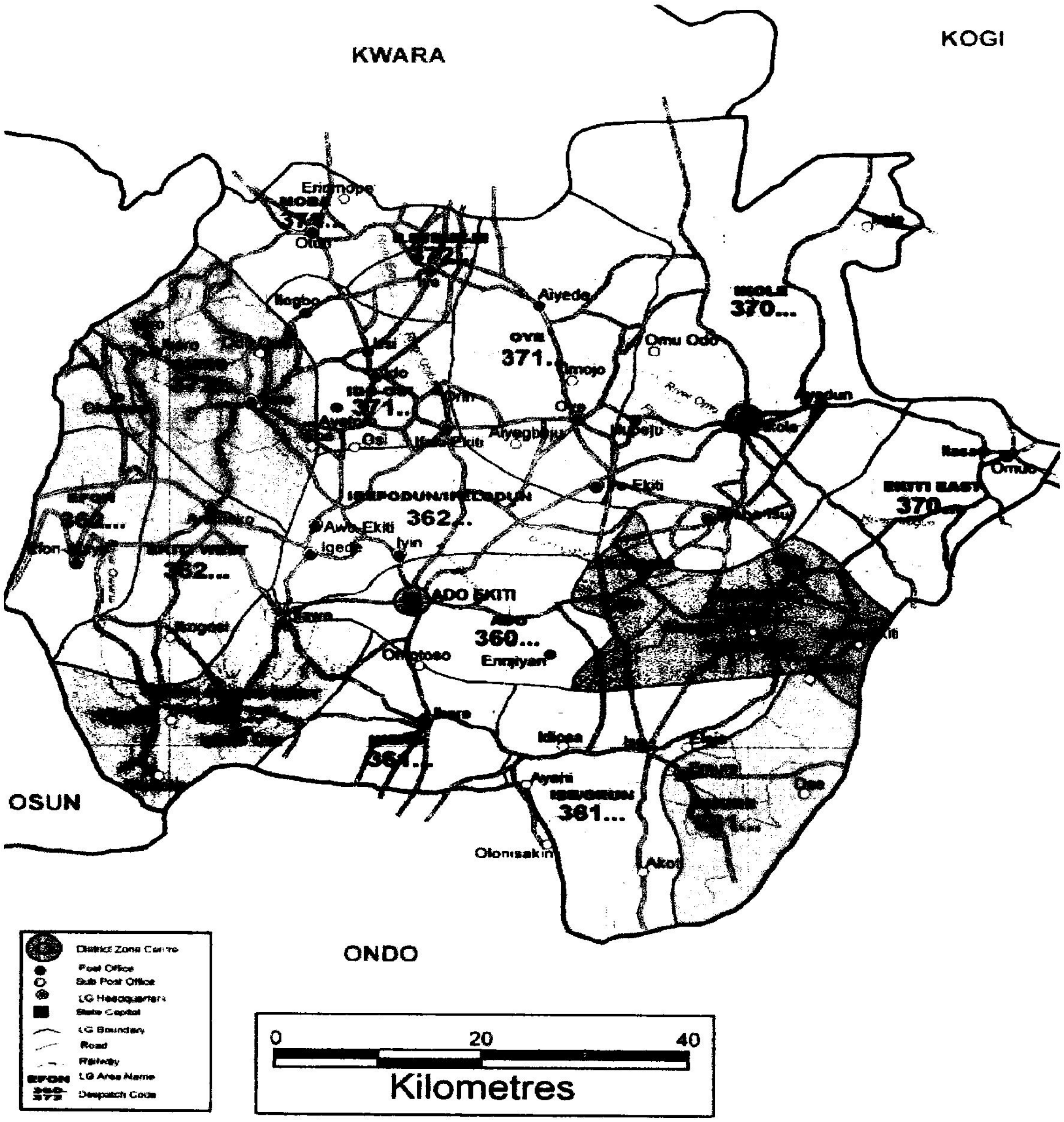
Furthermore, in many smallholder farming communities, especially in developing countries, the only link farmers have to knowledge-based assets and technological innovations on sustainable soil management is through extension services. Since the role of extension officers is to facilitate and transfer scientific ways of farming, they are often found overwhelmed by the number of communities they are responsible for. This impedes the efficacy of attending to the needs of all farmers and hampers the adoption of soil conserving practices. Therefore, weak institutional capacity leads to lack or the unreliability of climate adaptation information which, combined with weather variability, will place food security in many developing countries under considerable stress (Antwi-Agyei, 2012).

Sufficient knowledge of the different available options is also crucial for farmers to make informed decisions on the best management strategies (Lee, 2007). A significant aspect in relation to the knowledge barrier is that in some cases, it's not as much about what knowledge is being transmitted to the farmer, rather than who is transmitting it. In a survey conducted by Takahashi *et al.* (2016), many surveyed farmers expressed skepticism about the accuracy of information from certain sources, namely those that are politically affiliated, and highlighted the need for access to information from reliable, consistent, objective and apolitical sources. It is generally desirable and even expected that farmers be a part of panels or commissions on sustainable soil management and for policy formation, since farmers themselves, along with cooperative extension agents, is deemed the most reliable sources for local information (Takahashi *et al.*, 2016).

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. DESCRIPTION OF STUDY SITE



The study area was Ikole-Ekiti (7° 80'N, 5° 29'E), in the derived savanna zone of Ekiti State, Nigeria. Is characterized by gentle undulating plain topography with an increasingly sparse natural vegetation and binomial rainfall pattern with mean annual rainfall of 1313 mm and average annual temperature of 24.2 °C. The soils of Ikole-Ekiti are Alfisols developed from Pre-Cambrian basement complex rocks containing deeply weathered granite gneiss, migmatites gneiss and charnockites with some underlain by iron pan to varying depths (Oladapo and Ayeni, 2013, Adeyeri *et al.*, 2017).

3.2. FIELD WORK

3.2.1. DESCRIPTION AND CHARACTERIZATION OF SITES

The study was conducted on various land- uses with different elevations viz:

1. Upper slope
2. Middle slope
3. Lower slope

Agricultural Land-use Types

I. Arable crop land (about 2.0 Ha) at FUOYE (Ikole-Ekiti Campus)

II. Tree crop plantation of Oil palm and few plantain (about 1.5 Ha)

3.2.2. SOIL MAPPING AND SAMPLING FOR SOIL CARBON STUDY

At each location, three topographic units were identified as upper slope, middle slope and lower slope at 50 m apart. A mini pit of 150 cm by 100 cm by 60 cm in length, breadth and depth, were dug and marked into delineated horizons of 0-20, 20-40 and 40-60 cm depths. At each delineated horizon, separate soil samples were taken from three separate sides to the mini- serve as replicates. A total of 54 soil samples were collected in well labeled polythene bags for laboratory analysis.

3.2.3. LABORATORY ANALYSES

Collected soil samples were air dried, crushed, sieved through 2 mm sieve and put in a freshly labeled bags. The soil samples were analyzed using the procedures described in Udo *et al.*, (2009) to determination the following physical and chemical properties: particle size distribution, pH, Total Organic Carbon, Total Nitrogen, Basic cations (Ca, K, Mg and Na), cation exchange capacity, exchangeable acidity and phosphorus.

Soil pH (water): This was determined in water at a soil/water ratio of 1:1 using digital pH meter

Apparatus

pH meter, 200ml beakers, stirring rods/Spatula, Washing bottle

Reagents

Standard buffer solutions (pH 4 and 7)

Procedures

Weigh 10g of 2mm sieved soil into a beaker and 20ml of distilled water, then stir thoroughly with a stirring rod and allow the suspension to stand for 30 minutes with occasional stirring. The electrode pH was inserted into the partially settled suspension inside the beaker and the pH was measured without stirring.

Available P: This was determined using Bray I method as described by Bray and Kurtz (1945).

Procedure Weigh 5g of soil which has passed through 2mm sieve, then add 35ml of extracting solution, thereafter you shake for one minute and filter. Determine P using Spectrophotometer.

Exchangeable acidity

Procedure

Procedure

Extraction with 1MKCL

1. Weigh 5g of air-dry soil into a 250ml conical flask and add 100ml extracting solution. Shake for one hour.
2. Filter into 100ml volumetric flask and make it up to mark with 1MKCl

Determination of H+ and Al (Exchangeable acidity)

Pipette 25ml of KCl extract into 250ml flask (use 50ml if pH of soil is above 5.0), add approximately 100ml of distilled water. Add 5 drops of phenolphthalein indicator, and titrate the solution with 0.01 NaOH to a first permanent pink end-point with alternate stirring and standing. Carry out blank titration 25ml of 2M KCl. The amount of base used is equivalent to the total amount of acidity (H^{-}+ Al) in the aliquot taken. Correct for a blank or NaOH titre on 25ml KCl solution. To the same flask, add 1 drop of 0.01M HCl to bring the solution back to the colourless condition, and add 10ml of NaF solution. While stirring, the solution constantly, titrate the solution with 0.01M HCl until colour of the solution just disappear and does not return within 2 minutes, the mMol, of acid used are equal to the amount of exchangeable Al. Subtract this value from the mMol, of total acidity from the first titration to obtain the mMol exchangeable H^+.Express the exchangeable H^+ and Al in mMol. Per 100g of soil mMol/100g= cMol/1kg

Soil organic carbon: The organic carbon was determined using potassium dichromate method (Walkley and Black, 1934) and multiplied factors by a factor of 1.724 (Nelson and Sommers, 1996) to obtain the per cent soil organic matter.

0.5g of sieved soils was weighed into 250ml conical flask and 10ml of 1N $k_2Cr_2O_7$was added, 20ml of conc $H_2SO_4$was also added and mixed, then allowed it to stand to cool down for 30min and added 200ml distilled water. The suspension was filtered and 3 drops of indicator was added, and afterward titrated the filtrate with0.4 N$(NH_4)SO_4FeSO_4.6H_2O$.An end point is then gotten, that is from dark green through blue to maroon colour.

Calculations

If X ml 0.4$(NH_4)2SO_4FeSO_4.6H_20$ were used for titration of the dichromate solution.

$$\text{Organic carbon (g/kg of soil)} = \frac{meqofCr2O7-meqFe-NH4-5o4}{weightofsample} * 100$$

SOM (g/kg of soil) = Organic Carbon * 1.72

Total Nitrogen: this was determined using Macro Kjeldahl method described by Jackson (1958).

Weigh about 1g of the soil sample into 500ml macro kjeldahal flask and 20ml concentrated H_2SO_4 with 1g catalyst mixture per sample. Heat the flask with content on the digestion stand until the solution becomes clear and soil residue remaining in white, heat further for few minutes to ensure complete digestion. The duration of heating depends on the material and type of heater employed. Allow cool, adding about 50 ml distilled water and mixing well, allow cooling again, decanting or filtering. Transfer to 100l volumetric flask and bring it up to 100ml mark with distilled water. Carry out blank digestion (all the reagents but without sample make up 100ml and determine nitrogen as well). Nitrogen is covered to ammonia and reacted with H_2SO_4 to form $(NH_4)_2SO_4$.

Exchangeable bases (Ca, K, Mg, and Na): These were determined by extracting soil samples with 1N NH_4OA_C.

Procedure

Weigh 10g of air dry soil sample (sieved through 2 mm sieve) and add one hundred (100ml of extracting solution(1MNH_4OAc), then shake for one hour or soak overnight, filter and make up to 100ml with NH_4OAc. From the filtrate, determine the exchangeable bases Ca, Mg, K, Na, by flame emission. While Ca and Mg are determined by EDTA titration or AAS the TEB are calculated in cMol/kg.

Particle size analysis: this was determined using hydrometer method (Bouyoucos, 1951).

The hydrometer method as described by bouyoucos (1962) was used for the particle size analysis. This explain the textural class of the soil under the different location, it gives the percentage sand, silt and clay.

50g of sieved soil was measured inside a container and 25mil of calgon was added and shook with mechanical shaker for 5min, the suspension was transferred to a 1-l capacity cylinder and dilute to the mark, it was then stirred for few minute with plunger and the first hydrometer reading was taking after 40sec. also, first temperature was taken using the thermometer. After 2hours, the second hydrometer reading and temperature two was taking.

NB: Blank was also prepared following the above procedures. The blank constitute of only water.

3.3. STATISTICAL ANALYSIS

The data collected were subjected to analysis of variance (ANOVA) procedure using the Randomized Complete Block Design (RCBD) and means separated using Least Significant Difference (LSD). The variations in soil organic carbon contents were statistically ranked using the coefficient of variation (CV) according to Wilding et al. (1994) as low variation (CV < 15%), medium variation (CV = 15 - 35%) and high variation (CV > 35%). Pearson correlation were used to establish relationships between the SOC contents and depth, toposequence and selected soil properties.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1. PHYSICAL AND CHEMICAL PROPERTIES OF AGRICULTURAL SOILS IN IKOLE-EKITI

The mean particle size distribution values with their respective standard deviations are presented in Table 1. The soils under arable cropping were of sandy loam textural class, having average percentage of 74.86% sand, 6.74% silt and 16.39% clay. The soils from the oilpalm production farmland were loamy sand with mean values of 81.19, 8.34 and 10.47% sand, silt and clay fractions, respectively. The particles distributed did not follow a consistent trend down the depths. The highest sand content of arable land was observed at 20-40 cm, highest silt at 40-60 cm and the highest clay at 0-20 cm depth while the oil palm had the highest sand content at 0-20 cm, highest silt at 0-20 cm and highest clay at 40-60 cm depth. Despite the fact that texture is an inherent soil property, management practices may have contributed indirectly to the the 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 the surface and subsurface layers during continuous tillage activities(Akinola and Olubanjo, 2017). Therefore, differences in particle size distribution can be due some farming practices such as continuous tillage or cultivation and intensive grazing , this was equally observed by (Yeshaneh, 2015).

The chemical properties of the studied soils are presented on Table 2. The pH ranges from 5.99 in arable soil to 6.47 in oilpalm plantation, with average of 6.18 and 6.51 respectively. The arable soils were characterized with slightly acid soil reaction while oilpalm production soil has a neutral soil reaction. The total nitrogen content ranges from 0.16% in arable soil to 0.24% in oil palm plantation, with average of 0.19 and 0.23 in arable and oil palm farmland respectively. The

Nitrogen content slightly followed a similar pattern as the SOC content which is expected as most soil nitrogen is bound in organic matter (Khresat *et al.* 2008). Available phosphorus decreased with soil depth in both arable and oilpalm land use, ranging from 4.47 $mgkg^{-1}$ in the oil palm to 6.71$mgkg^{-1}$ in the arable farmland, with mean 6.23 and 5.33 $mgkg^{-1}$ respectively.

Table 1. Depth-wise means and standard deviations of physical properties of soils under two agricultural land use types in Ikole-Ekiti (N = 9)

Land use	Depth	Sand	Silt	Clay	Textural class
	(cm)		(%)		
Arable	0 -20	75.14 ± 0.69	8.21 ± 2.01	16.65 ± 9.08	Sandy loam
	20-40	75.36 ± 7.52	8.10 ± 1.45	16.54 ± 8.18	Sandy loam
	40-60	74.09 ± 8.10	9.92 ± 5.14	15.99 ± 7.11	Sandy loam
	Mean	74.86	6.74	16.39	Sandy loam
Oilpalm	0 -20	80.97 ± 7.62	8.88 ± 2.50	10.15 ± 7.10	Loamy sand
	20-40	82.23 ± 6.12	8.05 ± 2.37	9.72 ± 4.28	Loamy sand
	40-60	80.37 ± 4.36	8.09 ± 2.44	11.54 ± 2.93	Loamy sand
	Mean	81.19	8.34	10.47	Loamy sand

Table 2. Depth-wise means and standard deviations of chemical properties of soils under two agricultural land use types in Ikole-Ekiti (N = 9)

Land use	Depth (cm)	pH	Nitrogen	Avail. P	Ca	K S	Mg	Na	E Acidity	CEC	ECEC	Base Sat.
			(%)	(mg kg^{-1})	(cmol kg^{-1})							(%)
Arable	0-20	6.44 ± 0.27	0.20 ± 0.10	6.71 ± 3.22	0.71 ± 0.28	0.09 ± 0.05	0.38 ± 0.11	0.15 ± 0.11	0.85 ± 0.18	1.33 ± 0.30	2.18 ± 0.37	61.01 ± 6.91
	20-40	5.99 ± 0.43	0.21 ± 0.08	6.47 ± 3.90	0.61 ± 0.15	0.10 ± 0.04	0.40 ± 0.10	0.17 ± 0.12	0.89 ± 0.21	1.28 ± 0.19	2.17 ± 0.19	58.99 ± 8.55
	40-60	6.11 ± 0.48	0.16 ± 0.10	5.50 ± 3.08	0.64 ± 0.21	0.10 ± 0.04	0.43 ± 0.98	0.18 ± 0.10	0.82 ± 0.24	1.35 ± 0.21	2.17 ± 0.31	62.21 ± 7.93
	Mean	6.18	0.19	6.23	0.65	0.10	0.40	0.17	0.85	1.32	2.17	60.74
Oilpalm	0-20	6.47 ± 0.41	0.23 ± 0.09	5.79 ± 3.22	0.90 ± 0.41	0.05 ± 0.01	0.42 ± 0.18	0.07 ± 0.05	0.92 ± 0.40	1.45 ± 0.60	2.37 ± 0.94	61.18 ± 7.86
	20-40	6.43 ± 0.41	0.24 ± 0.10	5.74 ± 2.57	0.92 ± 0.42	0.05 ± 0.02	0.43 ± 0.19	0.06 ± 0.06	0.81 ± 0.20	1.47 ± 0.57	2.28 ± 0.76	64.48 ± 5.24
	40-60	6.62 ± 0.37	0.23 ± 0.08	4.47 ± 2.34	1.10 ± 0.45	0.05 ± 0.01	0.43 ± 0.14	0.05 ± 0.02	0.89 ± 0.32	1.64 ± 0.54	2.53 ± 0.54	64.82 ± 12.98
	Mean	6.51	0.23	5.33	0.97	0.05	0.43	0.06	0.87	1.52	2.39	63.49

OC = Organic carbon; OM = Organic matter; Ex. A = Exchangeable acidity; CEC = Cation exchange capacity; ECEC = Effective cation exchange capacity and %BS = Percent Base Saturation

The decrease of available phosphorus down the slope can be as a result of leaching. The means of exchangeable bases (Ca, K, Mg and Na) means were 0.65, 0.10, 0.40 and 0.17 cmol.kg^{-1} respectively in arable farmland and 0.97, 0.05, 0.43, 0.06 cmol.kg^{-1} in oil palm farmland. The mean of exchangeable acidity was 0.85 cmol. kg^{-1} and 0.87 cmol.kg^{-1} in arable and oil palm farm land respectively. Soil CEC has been classified as low (<6 cmol.kg^{-1}), medium(6-12 cmol. kg^{-1}), and high (12 cmol. kg^{-1}) for some Nigeria soils Ezeaku *et al*: (2012). On the basis of this classification, the mean CEC is low for both land uses at 1.32 and 1.52 cmol.kg^{-1} in arable and oil palm farmland respectively. The low CEC suggest low buffering capacity and is a cause for concern as both landuse types with low CEC can be cataloged as unsustaianable land use due to kaolinite in fine earth fraction (Spark, 1995). The ECEC ranges from 2.17 cmol. kg^{-1} in arable and 2.53 cmol. kg^{-1} in arable and oil palm respectively with mean of 2.17 cmol. kg^{-1} and 2.39 cmol. kg^{-1} in arable and oil palm respectively. The base saturation was 60.74% and 63.49% at arable and oilpalm farmland respectively. The results reveal that cultivation decreases soil nutrient levels, which has been reported by many researchers (Lepsch et al., 1994; Zheng et al., 1996).

4.2. EFFECTS OF SLOPE, DEPTH AND AGRICULTURAL LAND USE TYPE ON SOIL ORGANIC CARBON CONTENTS IN AGRICULTURAL SOILS IN IKOLE-EKITI

The average SOC contents in the derived savanna soils in Ikole-Ekiti under arable cropping and oilpalm production are presented on Table 3. The soil organic carbon contents of the soils varied from 0.35 % at depth 40-60 cm in the lower slope to 0.66 % at the same depth but in the middle slope. The SOC was below the 1.0% recommended by Esu *et al* (1991) and rated low. The generally lower SOC in agricultural soils in Ikole-Ekiti could be attributed to the derived savanna vegetation in combination with intense continuous cultivation. At the upper slope, SOC had the highest mean at depth 20-40 cm while the other slopes had the higher contents at the surface horizons. The SOC decreases as depth increases in the lower slope but follows inconsistent trends in the other topographical units. SOC generally showed high variations (CV > 35%) at all depths in the studied topographical units except at depth 20-40 cm in the middle slope. On average, middle slope had the highest SOC concentration with the lower slope recording the least value. However, SOC showed the lowest variation in the middle slope. The lowest SOC contents recorded at the lower slope could be due to more intense cropping activities, has this topographic unit is usually farmed year round resulting in low organic materials. These variations could be due to different management practices existing in these two land use types such as tillage practices that can alter the soil organic content. The research work is not agreeing with Vanden Bygaart (2001), using 137Cs methodology, who found that topsoil had been eroded from upslope positions, primarily from the shoulder, and deposited in down slope positions, mainly the foot slope.

Table 3. Effects of slope on average depth-wise contents of SOC in agricultural soils in Ikole-Ekiti (N = 9)

Slope	Depth (cm)	SOC (%)	Std. Dev.	CV (%)
Upper	0-20	0.53	0.31	58.72
	20-40	0.63	0.43	63.08
	40-60	0.39	0.41	106.74
	Mean	0.52	0.38	76.18
Middle	0-20	0.62	0.25	40.89
	20-40	0.61	0.19	30.90
	40-60	0.66	0.45	68.38
	Mean	0.63	0.30	46.72
Lower	0-20	0.50	0.44	90.00
	20-40	0.44	0.39	88.24
	40-60	0.35	0.29	81.24
	Mean	0.43	0.37	86.49

Table 4 presented the depth-wise distribution of SOC in agricultural soils in Ikole-Ekiti in relation to agricultural land use type and management. In both arable cropping and oil palm production systems, the SOC showed high variations (CV ranged from 52.63 – 105.44 %) and decreased with increasing depth. The result showed that the SOC contents of agricultural soils in Ikole-Ekiti is on the average of 0.53 %, irrespective of the land use type. The lowest soil organic carbon in cultivated fields could be due to low organic matter inputs coupled by reduced physical protection of SOC as a result of tillage and increased oxidation of soil organic matter. This was in agreement with John *et al.* (2005) who reported an increasing SOC concentration in the A horizons in the order arable soils < grassland soil <forest soil. The result of the present study is also in conformity with the findings of many other authors (Dawit*et al.*, 2002; Celik, 2003; Merino *et al.*, 2004; Heluf and Wakene, 2006; Gebeyaw, 2007) elsewhere.

Table 4. Depth-wise means, standard deviations and coefficient of variation of SOC in soils of two agricultural land use types in Ikole-Ekiti (N = 9)

	Depth(cm)	SOC (%)	Std. Dev.	CV (%)
Arable	0-20	0.55	0.38	69.31
	20-40	0.62	0.39	64.04
	40-60	0.42	0.44	105.44
	Mean	0.53	0.40	79.60
Oilpalm	0-20	0.54	0.29	52.63
	20-40	0.54	0.31	57.88
	40-60	0.52	0.36	70.06
	Mean	0.53	0.32	60.19

The interactive effects of slope and depth on the SOC contents of agricultural soils in Ikole-Ekiti in relation to agricultural land use types and management practices were presented in Table 5. In soils under arable cropping, the SOC contents ranged from 0.25 – 0.66 % at 40-60 cm depth in upper slope and 20-40 cm depth in middle slope, respectively. The SOC decreases with depth increase even though depth 20-40 cm had higher SOC contents than the surface horizons in both upper and middle slopes.

In Oilpalm production farmland, the SOC had the lowest mean value of 0.31% at 40-60 cm depth in the lower slope and the highest (0.72%) at 20-40 cm in the upper slope. At the lower slope, the SOC decreased with increasing depth but reverse was the case in the middle slope except at depth 0-20 cm, while the upper slope showed a varying trend. This research agrees with the report of SOC to be greatest at the surface and declines rapidly with depth in various land uses namely woodland, agricultural field and fallow field (Lemenih and Itanna 2004; Walker and Desanker, 2004; Yimer *et al.* 2007)

Generally, middle slope recorded the highest mean values of SOC in agricultural soils from both studied land use types which can be due to tillage practices.

In both agricultural land use types studied, the SOC were not significantly different both at slope levels and at soil depths and only lower slopes recorded higher SOC contents at the surface soil depths.

Table 5. Interactive effects of slope and depth on mean values of soil organic carbon (SOC) in soils under two agricultural land use types (N = 9)

Landuse	Slope	Depth (cm)	SOC (%)
Arable	Upper	0-20	0.48
		20-40	0.65
		40-60	0.25
	Middle	0-20	0.59
		20-40	0.66
		40-60	0.61
	Lower	0-20	0.59
		20-40	0.54
		40-60	0.39
Oilpalm	Upper	0-20	0.57
		20-40	0.72
		40-60	0.52
	Middle	0-20	0.65
		20-40	0.55
		40-60	0.71
	Lower	0-20	0.41
		20-40	0.35
		40-60	0.31

4.3. RELATIONSHIPS BETWEEN THE SOC AND SOIL PROPERTIES IN THE STUDIED AGRICULTURAL LAND USE TYPES

The correlation relationships between the SOC and other properties of the agricultural soils studied were presented in Table 6. The SOC showed a perfect significant correlation ($r = 1.00^{**}$ at $p < 0.01$) with organic matter (OM), confirming that OM contributes perfectly to SOC concentration in the soils. SOC also correlated significantly with Ca (0.331^{*}), CEC (0.301^{*}) and ECEC (0.346^{*}), all at $p < 0.05$ probability level. SOC also increases with sand ($r = 404^{**}$) but decreases with increasing clay contents ($r = -0.413^{**}$) in the soils studied. However, SOC showed a negative non-significant relationship ($r = -0.227$) with pH, a factor that influenced many other soil properties.

Table 6. Combined correlation matrix of soil properties in the studied agricultural land use types

	pH	SOC	OM	Av. P	Mg	Ca	Na	N	K	Clay	Silt	Sand	Ex. A	CEC	ECEC	% BS
pH	1															
SOC	-.227	1														
OM	-.227	1.00**	1													
Av. P	.407**	.235	.235	1												
Mg	.365**	-.085	-.086	-.192	1											
Ca	.434**	.331*	.331*	-.125	.527**	1										
Na	-.278*	.137	.136	.142	-.081	-.332*	1									
N	.317*	-.037	-.037	-.042	.160	.196	-.163	1								
K	-.316*	.147	.146	.062	-.201	-.341*	.736**	-.054	1							
Clay	-.064	-.413**	-.414**	-.078	.133	-.002	.033	-.052	.189	1						
Silt	-.012	-.017	-.017	-.124	.311*	.178	.216	.042	.146	-.095	1					
Sand	.066	.404**	.404**	.122	-.247	-.067	-.114	.034	-.238	-.925**	-.290*	1				
Ex. A	-.044	.253	.252	-.094	.160	.249	.087	-.022	.145	-.175	.239	.076	1			
CEC	.397**	.301*	.300*	-.130	.730**	.917**	-.020	.178	-.104	.064	.312*	-.181	.296*	1		
ECEC	.283*	.346*	.345*	-.143	.630**	.814**	.025	.126	-.013	-.031	.348**	-.103	.685**	.899**	1	
% BS	.362**	.050	.050	-.006	.438**	.507**	-.052	.204	-.183	.192	.032	-.197	-.614**	.545**	.133	1

* and **. Correlation is significant at the 0.05 and 0.01 level (2-tailed).

OC = Organic carbon; OM = Organic matter; Ex. A = Exchangeable acidity; CEC = Cation exchange capacity; ECEC = Effective cation exchange capacity and %BS = Percent Base Saturation

CHAPTER FIVE

5.0. SUMMARY AND CONCLUSION

The results show that the mean SOC content of agricultural soils in Ikole-Ekiti was 0.53 %, irrespective of the land use type. Generally, the middle slope recorded the highest mean values of SOC in the two land use types. In both agricultural land use types, the SOC was not significantly different at slope levels and at soil depths and only lower slopes recorded higher SOC contents at the surface soil depths. The SOC showed a perfect significant correlation ($r = 1.00^{**}$ at $p < 0.01$) with organic matter (OM), confirming that OM contributes perfectly to SOC concentration in the soils.

In conclusion, this study shows that the depth, topography and land use did not affect the soil organic carbon content in the studied area. Therefore, it is recommended that conservation tillage practices, crop residue management and addition of manure and compost should be introduced and practiced consistently which will help to increase and maintain soil organic content in the soil.

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