The impact of tillage, cowpea-maize rotation and mulching on the physicochemical properties of a Haplic Plinthosol in Ghana

BY

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BSc. (Hons) Agriculture

MPhil. Land Use and Environmental Science

DECEMBER, 2015

The impact of tillage, cowpea-maize rotation and mulching on the physicochemical properties of a Haplic Plinthosol in Ghana

A Thesis presented to the Department of Crop and Soil Sciences, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana in partial fulfillment of the requirements for the award of the degree of

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IN

SOIL SCIENCE

BY

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BSc. (Hons) Agriculture

MPhil. Land Use and Environmental Science

DECEMBER, 2015

DEDICATION

To the smallholder farmer in sub-Saharan Africa

DECLARATION

I hereby declare that this submission is my own work toward the PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The study was carried out on a Haplic Plinthosol at the Faculty of Agriculture Research station, Anwomaso in the semi-deciduous forest zone of Ghana for two years to assess the impact of tillage, crop rotation and mulching on selected soil physical, hydrophysical and chemical properties, grain and stover yields of maize and cowpea. The experiment was a split-split plot arranged in randomized complete block design (RCBD) with three replications. Tillage treatments were assigned to the main plots and consisted of conventional-no-tillage rotation (CT – NT) and continuous conventional tillage (CT – CT). In the sub plots were, cowpea-maize rotation (C – M), maize monoculture (M – M) and cowpea monoculture (C – C). Crop residue mulch that is, mulch (+R) and no mulch (-R) were assigned to the sub-sub plots. Maize and cowpea were used as test crops. The results of soil physical parameters indicated significantly ($P < 0.05$) lower soil bulk density and higher total porosity under the treatment interactions, conventional-no-tillage rotation x cowpea-maize rotation or maize monoculture x mulch. Soil penetration resistance increased with time and ranged between 500.1 and 1079.6 kPa with practices that included conventional-notillage rotation and mulch recording significantly ($P < 0.05$) lower values in both years of study. On the other hand, treatment effect on dry and wet aggregate size distribution and stability followed a consistent trend with conventional-no-tillage rotation x maize monoculture or cowpea-maize rotation x mulch recording higher fraction of large aggregates and stability than continuous conventional tillage x cowpea monoculture x no-mulch at both the 0 – 15 and 15 – 30 cm depths. Saturated

hydraulic conductivity ranged between 5.40 and 16.74 cm h^{-1}. Continuous conventional tillage x maize monoculture x mulch significantly increased saturated hydraulic conductivity than conventional-no-tillage rotation x cowpea-maize rotation x mulching. Sorptivity, steady state infiltrability and cumulative infiltration amount ranged between 24.7 and 167.1 mm $s^{-1/2}$, 0.14 and 0.53 mm s^{-1}, and 377 and 2823 mm respectively. These were significantly higher under conventional-no-tillage rotation x cowpea-maize rotation and mulching. Soil moisture storage increased with soil depth and was significantly higher in the 0 – 15 cm depth under continuous conventional tillage x cowpea-maize rotation x mulching. Meanwhile in the 15 – 30 cm depth, significantly higher soil moisture was noted under conventional-no-tillage rotation x cowpea-maize rotation x mulching. Soil organic carbon ranged between 1.54 – 1.86 % and 1.06 – 1.48 % respectively in the 0 – 15 and 15 – 30 cm depths. The effect of treatment interactions on soil organic carbon indicated significantly ($P < 0.05$) higher values under conventional-no-tillage rotation x cowpea-maize rotation x mulching at the 0 – 15 and 15 – 30 cm depths.

Particulate organic carbon decreased with soil depth and was 3.71 g kg^{-1} (0.371 %) soil and 2.44 g kg^{-1} (0.244 %) soil at the 0 – 15 and 15 – 30 cm depths respectively. Water extractable organic carbon decreased with soil depth and was 13.95 mg kg^{-1} (0.01395 %) soil and 10.73 mg kg^{-1} (0.01073 %) soil at the 0 – 15 and 15 – 30 cm depths respectively. Water extractable organic carbon was significantly ($P < 0.05$) higher under conventional-no-tillage rotation x cowpea-maize rotation x mulch at the two depths, the former treatment interaction together with conventional-no-tillage rotation x maize monoculture x mulch and conventional-no-tillage rotation x maize monoculture x no mulch showed significantly ($P < 0.05$) higher impact. Mineralized carbon also decreased with soil depth and was 0.85 mg CO_2 g^{-1} (0.085 %) and 0.54 mg

CO_2 g^{-1} (0.054 %) in the 0 – 15 and 15 – 30 cm depths respectively. It was significantly ($P < 0.05$) higher under continuous conventional tillage x cowpea-maize rotation x mulch, continuous conventional tillage x cowpea monoculture x mulch and continuous conventional tillage x cowpea monoculture x no mulch in the 0 – 15 cm soil depth. In the 15 – 30 cm depth, however, significantly ($P < 0.05$) higher mineralized carbon was noticed under conventional-no-tillage rotation x maize monoculture x mulch, conventional-no-tillage rotation x cowpea-maize x mulch and continuous conventional tillage x cowpea monoculture x mulch. Maize grain yield increased in the second year of the study with values ranging between 3.32 and 4.69 Mg ha^{-1} compared to 1.83 and 4.13 Mg ha^{-1} in the first year. The results showed significant differences in the impact of treatment interactions with higher values recorded under conventional-no-tillage rotation x cowpea-maize rotation x mulch and continuous conventional tillage x cowpea-maize rotation x mulch in both years of study. Cowpea grain yield ranged from 0.17 – 3.32 Mg ha^{-1} in 2013 and 0.61 – 2.03 Mg ha^{-1} in 2014 with significantly higher values recorded under conventional-no-tillage rotation x cowpea monoculture x no mulch and continuous conventional tillage x cowpea-maize x mulch in the former and latter years respectively. Conventional-no-tillage rotation in combination with cowpea-maize rotation or maize monoculture and mulch is recommended for the potential of its attributes for sustained crop production in the semi-deciduous forest zone of Ghana.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background and problem statement

The soil is a component of the environment which interacts with other system components through the exchange of feedbacks (Ghimire *et al*., 2007; Gao *et al*., 2013). Its functions include; water storage and purification, decomposition of organic materials, nutrient recycling and supply, and supporting of plant growth and food production (Singh and Kaur, 2012). From the agricultural perspective, the soil is considered as the main medium for plant growth (Karlen *et al*., 1994). Therefore, the soil continues to be manipulated diversely to enhance its services (water storage and nutrient supply) and make it favourable for crop production (Johansen *et al*., 2012).

However, neither all the methods nor approaches used to manipulate the soil have enhanced its functionality (Mchunu *et al*., 2011; Romaneckas *et al*., 2013). Soil degradation arising from surface runoff and erosion, soil fertility decline, soil nutrient imbalance, and increased drying and wetting cycles are but a few of the consequences limiting its productivity (Reynaldo *et al*., 2012). Thus, soil degradation increases cost of production and environmental management. Yet, because of the need for new skills among other things, letting off soil degrading practices remains a great challenge for smallholder farmers in sub-Saharan Africa (SSA) (Sanchez *et al*., 1997; Giller *et al*., 2009; Guto *et al*., 2011).

Nevertheless, if the techniques and practices used in soil manipulation were appropriate (Johansen *et al*., 2012; Miriti *et al*., 2013), soil degradation could be halted and/or reversed (Kurothe *et al*., 2014; Mason *et al*., 2014). The appropriateness of a crop production practice is relevant within a given environment, site, and crop type(s)

(Blanco-Canqui and Lal, 2009).
Tillage, crop rotation and crop residues retention as mulch are among the well-studied crop production practices used in soil management (Larney *et al*., 2003; Mutegi *et al*., 2010; Feng *et al*., 2011). However, most studies on tillage have compared and contrasted conventional and conservation tillage systems (Blanco-Canqui *et al*., 2004; Tan *et al*., 2007; Himmelbauer *et al*., 2012). But the appropriateness of tillage rotation and/or shifts in tillage practices in soil management have been scarcely considered. Tillage rotation has the potential to decrease tillage frequency, minimize soil compaction from machinery and enhance soil aggregation (Hou *et al*., 2012).

In the meantime, the frequency and intensity of conventional tillage has immensely contributed to pulverizing soil aggregates, declining soil fertility, facilitating surface runoff, erosion and soil loss thus predisposing the soil to degradation (Lampurlane´s and Cantero-Martı´nez, 2003; Altikat *et al*., 2012; Myburgh, 2013). Consequentially, practices that reduce tillage, protect soil surface and enhance soil condition have been promoted for adoption (Venterea and Stanenas, 2005; Johansen *et al*., 2012). But, smallholder farmers in SSA have not adopted conservation tillage systems entirely (Giller *et al*., 2009; Hobbs, 2007) for some known reasons such as resource constraints and lack of new skills (Du *et al*., 2010; Saha *et al*., 2010).

In consonance with these observations, some research reports have indicated the need for some conservation tillage systems to occasionally benefit from conventional tillage practice (Arvidsson *et al*., 2012; Sharma and Abrol, 2012; Ajayi and Aruleba, 2014). In the light of this, the study suggests that there is the plausibility for complementarity when tillage practices are rotated. Additionally, not many studies have been conducted on tillage rotation. It is therefore necessary to evaluate the impact of conventionalconservation tillage rotation on soil properties and crop yield.

Crop rotation is an important cropping practice used in soil management because of its contribution to the amount and diversity of crop residues returned to the soil (Davis *et al*., 2012), soil structural stability, and diversity of soil microorganisms (Sainju *et al*., 2012). However, the impact of crop rotation may vary depending on the intensity of rotation, soil type, sequence of crops and availability of plant nutrients (Kumar *et al*., 2012; Perez-Brandan *et al*., 2014).

Crop rotation involving legumes has the potential to minimize loss of soil fertility and sustain crop yield in low input cropping systems (Adjei-Nsiah, 2012). Though this attribution is made in relation to conservation tillage, other reports have shown significant increases in soil fertility of conventional tillage systems under crop rotation with legume (Vyas *et al*., 2013). This may suggest that crop rotation with legume has the potential to increase soil fertility across tillage practices. Meanwhile, Wright *et al*. (2007) indicated that the implication of crop rotation differs from one system to the other.

The diversity in scientific reports on crop rotation with legumes shows the importance for system and location specific evaluation of the practice. Also, not many of the available scientific reports have investigated effects of crop rotation on soil properties and crop yield as stand-alone, and with conventional-conservation tillage rotation. Such studies would allow for adaptation of practices to specific needs and offer the opportunity to select the most appropriate combination of practices beneficial to soil properties and crop growth and yield.

Retention of crop residues as mulch is an important component of soil management (Sadeghi and Bahrani, 2009). Mulches reduce runoff losses, increase water infiltration, conserve soil water and increase biological activity and soil organic matter content (Myburgh, 2013). Despite these benefits, residue removal, burning and incorporation which tend to leave soil surface bare and increase soil degradation are still popular among smallholder farmers (Ajayi and Aruleba, 2014). For its beneficial effects, conservation agriculture prescribes the maintenance of permanent soil cover (Thierfelder *et al*., 2012).

Nonetheless, the opportunity cost of retaining crop residues as mulch (depending on the residue amount) amongst other reasons, have militated against its massive adoption (Giller *et al*., 2009; Valbuena *et al*., 2012). Partial adoption of conservation agriculture practice mixed with traditional practice have been identified (Haggblade and Tembo, 2003; Bhattacharyya *et al*., 2015). Yet not many scientific evaluations of the benefits of crop residues used as mulch to sustainable soil management in conventionalconservation tillage practice have been conducted.

This study therefore envisages that conventional-conservation tillage rotation, its combination with crop rotation (involving legume) and mulching could provide a set of appropriate and alternate crop production practices with beneficial impact on sustainable soil management. Results of this study will contribute to minimizing soil degradation by reducing continuous conventional tillage and improving soil condition for increased crop yield. This will reduce the expenditure on erosion control and reduce cost of production.

It was hypothesized that the interaction of conventional-no-tillage rotation, crop rotation and mulching will complementarily enhance soil properties and crop yield compared to conventional tillage, monoculture and no-mulch. The study therefore aimed at improving the productivity of smallholder farmers through the conservation of soil resources by identifying beneficial soil management options for tillage-crop rotation- mulch system.

1.2 Specific objectives

The specific objectives were to:

i. evaluate the impact of tillage rotation, crop rotation and mulching on selected soil physical and hydro-physical properties.

ii. determine the impact of tillage rotation, crop rotation and mulching on organic carbon, particulate, extracted and mineralized carbon.

iii. assess the effect of tillage rotation, crop rotation and mulching on the yield of maize and cowpea.

1.3 Outline of the thesis

This thesis is structured in five chapters. The first chapter introduces the problem that necessitated the study, hypothesis and study objectives. In Chapter 2, a review of the effects of tillage, crop rotation and mulching with crop residues on selected soil physical and chemical properties is presented. At the end of this chapter, is a review summary. The materials used and methods followed in data collection, laboratory and statistical analyses are provided in Chapter 3. Chapter 4 is the presentation, and discussion of the results. Finally, Chapter 5 consists of the summary, conclusions and recommendations of the study.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The soil is a natural capital composed of resources and services (Sanchez *et al*., 1997). As a resource, it is non-renewable (Liu *et al*., 2006) yet, it remains the main source of nutrients, structural support and water supply for plant growth and yield (Wingeyer *et al*., 2015). Proper management of non-renewable resources through recycling, reusing and finding alternative options are among the known strategies for ensuring sustainable use (Sommer *et al*., 2014). It is therefore not surprising that soil nutrients mining through crop removal (IFPRI, 2002), among other soil degrading practices has yielded the presently depleted state of arable lands in sub-Saharan Africa (Umar *et al*., 2011). In view of this, many studies have been undertaken to identify appropriate alternative options with the potential to restore and sustain the productivity of soils in sub-Saharan Africa (Chatskikh *et al*., 2009; Lin, 2011). The review below highlights studies on three major crop production practices (tillage, crop rotation and crop residue mulch) and their impact on soil physical, hydrological, and chemical properties as well as maize and cowpea yield.

2.2 Tillage

2.2.1 Definitions

Tillage encompasses pre-planting operations that manipulate the soil to create a suitable medium for seed planting, emergence, growth and yield (FAO, 2001). According to ASAE (2005), tillage involves the modification of the soil for the enhancement of crop production. Lal (1983) defined tillage as the physical, chemical and biological manipulation of soil to optimize conditions for germination, seedling establishment and crop growth. In this study, tillage was considered as the seasonal and occasional physical manipulation of soil to create a suitable condition for crop growth and yield.

2.2.2 Functions of tillage

The functions of tillage include the following:

a. Manipulation of soil structure to create fine tilth suitable for seed germination and emergence (Mohammadi, 2011);

b. Destruction of weeds and pests (Imaz *et al*., 2010);

c. Incorporation and redistribution of plant nutrients (Imaz *et al*., 2010);

d. Regulation of soil organic matter and other soil biochemical properties (Mohammadi, 2011);

e. Regulation of soil moisture, soil aeration and soil temperature (Ajayi and Aruleba, 2014); and

f. Reduction in surface runoff (Govaerts *et al*., 2007).

2.2.3 Tillage methods

Tillage methods are grouped under two main headings which are conventional tillage and conservation tillage. The division is based on the proportion of crop residues left on the soil after tillage and the intensity of the tillage.

2.2.3.1 Conventional tillage

Conventional tillage is the manipulation of the soil to prepare the germinal layer for planting. The practice leaves < 15 % residue cover on the soil surface (Singh and Kaur, 2012), breaks large soil clods (Devine *et al*., 2014), increases soil aeration and enhances oxidation of macroaggregates-protected soil organic matter (Šimanský and Tobiašová, 2012).

Conventional tillage systems consist of the use of primary tillage, secondary tillage and/or their combinations at the same time or at different periods depending on the crop. In some conventional tillage systems, primary tillage is used in the early rainfall season and secondary tillage in the late or minor rainfall season (Spiegel *et al*., 2007) but in other systems, both primary and secondary tillage activities are carried out consecutively in the same season (Aikins and Afuakwa, 2012a).

Mechanical and animal traction have been used in the operation of conventional tillage implements depending on the availability (Mupangwa *et al*., 2011). The main primary tillage implement used in conventional tillage is the mouldboard plough and for secondary tillage, harrows have been used. The average ploughing depth attained with these implements range between 25 cm and 30 cm (Imaz *et al*., 2010) and the process involves at least one pass of mouldboard plough and two passes of a disc harrow (Rashidi and Keshavarzpour, 2008; Mohammadi, 2011).

Despite the immediate benefits to soil and crop, frequent use of conventional tillage increases soil erosion, loss of soil carbon, reduces biological diversity, leading to an overall decline in soil fertility and productivity (Six *et al*., 2000 ; Zhang *et al*., 2007; Oorts *et al*., 2007). Therefore, alternative practices that minimize such impacts are needed to sustain crop production.

2.2.3.2 Conservation tillage

Conservation tillage is described as any tillage or seeding system that leaves at least 30 % of the soil surface covered with crop residues (an equivalent of 1120.85 kg ha^{-1}) after planting (Daughtry *et al*., 2006). It is aimed at maintaining crop residues on soil surface to reduce erosion and increase soil water retention (van den Putte *et al*., 2012) but Hobbs (2007) argued that residue level alone could not sufficiently define conservation tillage because other variables including time, nutrient level, soil water, soil structure, fuel are also of essence.

Benefits of conservation tillage system include reduction in production cost, reduced soil erosion, increased soil organic matter, increased soil biological diversity, increased infiltration and aggregates stability, and increased hydraulic conductivity (Bescansa *et al*., 2006; Aflakpui *et al*., 2007; Du *et al*., 2010). However, the absence of tillage on soils with high penetration resistance and high bulk density results in poor yield for most smallholder farmers in sub-Saharan Africa (Sharma and Abrol, 2012).

The challenge therefore is to understand the impact of tillage frequency or regularity, tillage sequence or rotation or integrated tillage practices on soils in SSA. This is important because the strict definition of conservation tillage has not allowed a broader consideration of appropriate and less burdensome tillage practices. Conservation tillage practices include zero tillage, strip tillage, ridge tillage, mulch tillage, minimum tillage and reduced tillage.

2.2.3.2.1 No –Till / Zero tillage

No-till is the practice of eliminating tillage as a pre-planting activity except the narrow slits and/or strips created for seed sowing and fertilization. Therefore in no-till systems, less than 25 % of soil surface is disturbed (Singh and Kaur, 2012) and 70 % or more crop residues on soil surface is left undisturbed (Molindo and Nwachokor, 2010). The system is also called direct seeding or direct drill (Rashidi and Keshavarzpour, 2008). Because of its restrictive mixing of soil, no-till systems have the potential to increase organic matter accumulation, promote soil aggregation and stability (Kravchenko and Thelen, 2007). Delayed seed emergence, pests and diseases incidence are the common challenges associated with this system (Videnović *et al*., 2011). Implements used in no-till include; row cleaners, coulters, disk openers, in-row chisels, and roto-tillers.

2.2.3.2.2 Strip tillage

Strip tillage involves the mechanical manipulation of narrow strips of previously undisturbed no-till fields (Altikat *et al*., 2012). These strips serve as access points for seeding and placement of fertilizer (Johansen *et al*., 2012). The strips also allow direct contact between soil and atmosphere to facilitate soil warming and loss of excess moisture through evaporation compared to no-till (Al-kaisi and Yin, 2005). The system therefore improves water circulation, plant nutrient availability, and controlled oxidation of soil organic matter. Apart from the strips created, features of strip tillage are same as no-till.

2.2.3.2.3 Ridge till

Ridges are heaps of soil (Ogban *et al*., 2008) usually about 10 cm high above soil surface which serve as planting medium for both root and non-root crops. Spaces left between ridges are covered with crop residues. Ridge tillage involves redressing the tops of previous ridges by cultivation (Singh and Kaur, 2012). Ridge tillage is carried out using sweeps, coulters, disk openers and row cleaners.

According to Shi *et al*. (2012) ridge tillage was proposed as a compromise for the negative consequences of mouldboard plough and the challenges associated with notillage. While mouldboard plough disrupts soil structure leaving little or no residue for surface protection, high soil moisture and low temperature amidst incidences of pests and diseases characterize no-till practice (Mason *et al*., 2014).

The benefits of ridge tillage therefore include reduced soil compaction, early seed emergence and establishment, efficient drainage, reduced soil erosion and increased nutrient availability (Wang *et al*., 2008). However, under ridge till, nutrient materials like manure are left unincorporated resulting in high ammonia volatilization causing environmental nuisance.

2.2.3.2.4 Mulch till

Mulch till is a tillage system which disturbs the entire soil surface (full width) and partially incorporates crop residues but leaves more than 30 % soil surface covered after planting (USDA, 2011). Implements used for mulch tilling include chisels, rotary harrows, field cultivators and sweeps or blades. The system is efficient in controlling erosion and weeds. Sufficient crop residues must however be available for use to achieve results especially because of the disturbance created.

2.2.3.2.5 Minimum tillage

Minimum tillage is a conservation tillage practice that mixes soil and leaves sufficient residue (> 30 %) on soil surface as check against surface runoff. Imaz *et al*. (2010) described minimum tillage as the use of chisel plough to mix soil to the 15 cm soil depth without inversion and followed by a secondary tillage. But Lampurlane´s and

Cantero-Martı´nez (2003) identified the system as the working of soil with field cultivator to 15 cm soil depth.

However, Najafinehad *et al*. (2007) and Jacobs *et al*. (2010) explained minimum tillage as one that involves one pass of disk harrow or a rotary harrow to a depth of 5 cm depth. The use of hoes to plough soil surface to 10 cm soil depth and create small planting holes has also been expressed as minimum tillage practice (Ghuman and Sur, 2001; Ogban *et al*., 2008).

2.2.3.2.6 Reduced tillage

Reduced tillage involves any tillage system that leaves 15 – 30 % (an equivalent of 500 – 1000 kg ha^{-1}) residue cover after planting (Singh and Kaur, 2012). It comprises the loosening and mixing of the soil without inversion (Spiegel *et al*., 2007). This system of tillage is built upon reduction in the intensity and depth of tillage. It may involve two passes of disk harrow to 15 cm soil depth ahead of planting (Najafinehad *et al*., 2007), or one pass of a tine stubble cultivator to a depth of 10 cm (van Groenigen *et al*., 2010). The use of reduced tillage as a conservation tillage practice has been contested because of the percentage of surface cover left but Mupangwa *et al*. (2011) indicated that reduced tillage system (include ripper tine and planting basins) and mulch tillage are the corner stones of conservation tillage.

2.2.3.3 Tillage practices that compromise conventional and conservation systems

The need to reduce intensity of conventionally tilled systems has been widely expressed (Liu *et al*., 2006; Johansen *et al*., 2012). Ghimire *et al*. (2011) argued that repeated conventional tillage is the main cause of declining soil quality and reducing crop yield. But the call for reduction in tillage intensity is not necessarily a call for adoption of conservation tillage. This may explain why adoption of conservation tillage is low among smallholder farmers in SSA (Johansen *et al*., 2012; Mupangwa *et al*., 2012) and adopters implement only components of conservation tillage in addition to their own practices (Giller *et al*., 2009). Besides, smallholder farmers in SSA have the tendency to shift between cropping practices depending on available resources (Molindo and Nwachokor, 2010; Aikins and Afuakwa, 2012b).

Sharma and Abrol (2012) argued that conservation tillage fields must benefit from conventional tillage within 2 – 3 years especially for soils susceptible to surface sealing and crusting. Linden *et al*. (2000) explained a scenario where chisel ploughing or mouldboard ploughing were carried out in fall and no tillage used in spring. EriksenHamel *et al*. (2009) indicated that no-tillage plots were conventionally tilled during land preparation and no additional tillage was used on no-till plots in subsequent seasons. Also, Liu *et al*. (2006) and Tarkalson *et al*. (2006) stated that integration of tillage systems could sustain soil quality and crop production. Integrated tillage was explained to mean change in tillage practice in concurrence with crop rotation. Tillage rotation, or tillage sequence or integrated tillage system have been experimented by previous studies (Fenster *et al*., 1965; Hou *et al*., 2012; Vyas *et al*., 2013).

These studies suggest that tillage rotation may hold opportunities of sustainable land management for smallholder farmers in SSA. Therefore it is necessary to evalutate its implications on soil properties and crop yield as part of the search for appropriate crop production practices.

2.3 Effect of tillage on soil physical and hydrological properties

2.3.1 Effect of tillage on soil structure

Soil structure refers to the combination or arrangement of primary soil particles into secondary soil particles, units or peds. (Landon, 1991; Singh and Kaur, 2012). It is influenced by soil texture, organic matter content, moisture, fauna activity and season (Yvan *et al*., 2012). By its function, soil structure influences soil pore space, soil compaction, water infiltration, plant root development, aggregation, soil air, among others (Kihara *et al*., 2011). But it is difficult to measure soil structure directly. Therefore changes in measurable soil parameters (due to tillage) such as aggregate stability, organic matter content, bulk density are used as proxies (Zhang *et al*., 2007; Chen and Yang, 2013).

Tillage loosens the soil surface to create a suitable medium for planting (Myburgh, 2013). By loosening the soil surface, the soil structure is disrupted because of the disaggregation of large macroaggregates into small macroaggregates and microaggregates, and the relocation of soil aggregates (Jabro *et al*., 2011). The loosened aggregates become susceptible to further breakdown under the impact of water and wind erosion with further consequence of surface sealing and crusting (Devine *et al*., 2014). Sealed soil surfaces do not effectively conduct soil water or allow sufficient water infiltration and therefore facilitate increased runoff, erosion and sediment transport (Dam *et al*., 2005).

2.3.2 Effect of tillage on soil compaction

Soil compaction is often measured by monitoring soil bulk density, penetration resistance and hydraulic conductivity (Jabro *et al*., 2011). Tillage compacts soil through the compression force exerted by the movement of tillage implement.

However, some degree of compaction is needed for mechanical support, water storage and protection of soil carbon especially for sandy soils (Ampofo, 2006).

2.3.2.1 Effect of tillage on soil bulk density

Soil bulk density is defined as the mass of dry soil per unit volume (Chaudhari *et al*., 2013). The ideal bulk density for sandy, silty and clayey soils are <1.6 Mg m^{-3}, <1.4 Mg m^{-3} and <1.10 Mg m^{-3} respectively (USDA, 2008). Beyond these, root growth impedance may occur (Lampurlane´s and Cantero-Martı´nez, 2003 ; USDA, 2008). The influence of tillage on soil bulk density varies with soil depth (Al-Kaisi *et al*., 2005; Sessiz *et al*., 2010), days or time (Chen *et al*., 1994), pore space (Dörner *et al*., 2012), organic matter content (Aşkin and Özdemir, 1968), wetting and drying cycles and gravel content (Lampurlane´s and Cantero-Martı´nez, 2003).

By loosening the soil surface, conventional tillage reduces soil bulk density through increase in soil total porosity (Bescansa *et al*., 2006; Yvan *et al*., 2012). Higher bulk density has been reported under no-till than conventional tillage at the 0 – 20 cm depth by several authors (Osunbitan *et al*., 2005; Aikins and Afuakwa, 2012b). On the other hand, Jabro *et al*. (2011) reported a significantly lower bulk density in strip tillage at both 0 – 10 and 10 – 30 cm depths compared to conventional tillage. Sessiz *et al*. (2010) and Rãus *et al*. (2011) also observed marginally lower bulk density under notill than conventional tillage in a two year experiment whilst Sharratt *et al*. (2006) reported no significant differences between no-till and conventional tillage after 20 years. Grant and Lafond (1993) argued that the reducing effect of conventional tillage on soil bulk density is only evident at shallow soil depth (0 – 30 cm). Therefore soil bulk density may increase as soil particles reconsolidate after tillage (Logsdon and Karlen, 2004).

2.3.2.2 Effect of tillage on penetration resistance

Penetration resistance is used to express the force or pressure that plant roots exert to permeate the soil. Lampurlane´s and Cantero-Martı´nez (2003) indicated that the force measured may be about eight times less than that required by plant roots to permeate the soil. According to Grant and Lafond (1993), unrestricted root growth occurs below 2500 kPa whilst Shi *et al*. (2012) set it at < 2000 kPa.

Penetration resistance as an indicator of soil compaction is influenced by soil depth, soil water, soil organic matter, soil density, wetting and drying cycles. Blanco-Canqui *et al*. (2006), reported that 70% of variation in penetration resistance observed from their site in Ohio was explained by change in gravimetric water content. Fuentes *et al*. (2009) also observed that penetration resistance increased with decreased volumetric water content, an indication of an inverse dependent relationship. Landsberg *et al*. (2003) on the other hand reported that penetration resistance has a near linear and positive but insignificant relation with soil water content. This could mean that penetration resistance correlates with but not dependent on soil water.

Reports of tillage impact on penetration resistance are divergent. Osunbitan *et al*. (2005), Sessiz *et al*. (2010), Aikins and Afuakwa (2012b) and Khan *et al*. (2014) observed higher penetration resistance in no-till than conventional tillage whilst Shi *et al*. (2012) and Sharma and Abrol (2012) reported lower penetration resistance in the former than in the latter. On the other hand, marginal differences in tillage impact on penetration resistance was reported by Sharratt *et al*. (2006) and Saha *et al*. (2010).

The effect of tillage on penetration resistance also changes with time. As dispersed soil particles resettle and consolidate after tillage, the soil becomes compacted and penetration resistance increases. Olaoye (2002) observed that penetration resistance at sowing was significantly different among five tillage practices examined. However, this difference disappeared by harvest.

2.3.2.3 Effect of tillage on saturated hydraulic conductivity

Movement of water into the soil from the surface to deeper layers is influenced by soil macroporosity, the connectivity and continuity of the pores, pore geometry, organic matter content, soil bulk density and penetration resistance (Bhattacharyya *et al*., 2006; Eusufzai and Fujii, 2012). Soils with high hydraulic conductivity reduce surface runoff. Hydraulic conductivity suitable for agricultural soils have been reported to range between 1 – 15 cm h^{-1} (Brady and Weil, 2002).

The effect of tillage on saturated hydraulic conductivity could be positive, negative and negligible. The findings of Celik (2011) from an Arik clay soil showed that hydraulic conductivity was significantly higher in conventional tillage compared to reduced tillage and no-till systems. Celik (2011) attributed the result observed to the cracks and fissures present, low bulk density and low penetration resistance associated with tillage. Notwithstanding, Jabro *et al*. (2011) reported significantly higher hydraulic conductivity in strip tillage than conventional tillage. According to Bhattacharyya *et al*. (2006), higher saturated hydraulic conductivity associated with conservation tillage systems are attributable to the continuous transmission pores running from the soil surface to deeper layers, and higher stability of aggregates.

On the other hand, no significant differences in tillage impact on Ks was reported by Jin *et al*. (2009) and Khaledian *et al*. (2013). The effect of tillage on Ks may disappear with time after tillage (Strudley *et al*., 2008) because of particle resettlement and reconsolidation (Khaledian *et al*., 2013). This may account for absence of statistical differences in tillage impact on Ks.

2.3.3 Effect of tillage on infiltration

Infiltration of water into the soil is affected by initial soil water content, soil surface characteristics, macroporosity, bulk density, and aggregates stability (Kameníčková *et al*., 2012). The FAO categorized infiltration rate for soils as follows: low (< 15 mm h^{1}), medium (15 -50 mm h^{-1}) and high (> 50 mm h^{-1}) (Brouwer *et al*., 1985).

Initial infiltration, also called sorptivity, expresses the amount of water that permeates the soil without the influence of gravity (Raut *et al*., 2014) and final or steady state infiltration refers to the amount of water that infiltrates when the soil is already wet. Tillage impact on infiltration is dependent on cropping season and time after onset of rains (Thierfelder and Wall, 2009).

Jin *et al*. (2009), Saha *et al*. (2010) and Chen and Yang (2013) reported significantly higher sorptivity, total infiltration and steady state infiltration under no-till and reduced tillage compared to conventional tillage. Thus, crop production practices that increase biological activity and preserve bio-channels could increase water infiltration (Fuentes *et al*., 2009) and soil water content (Saxton and Rawls, 2006). Contrary views were shared by Khaledian *et al*. (2013) and Kumar *et al*. (2012) who also observed that conventional tillage increased sorptivity and total infiltration than no-till.

2.3.4 Effect of tillage on soil water retention

The amount of water in the soil is determined by soil texture, soil structure, macroporosity and organic matter content (Bhattacharyya *et al*., 2006). Soil water is important because it drives soil physico-chemical-biological activities which affect soil structure, aggregation, nutrient transport, temperature regulation, and expansion and contraction (Nagumo *et al*., 2006; Obalum *et al*., 2011; Romaneckas *et al*., 2013).

A report of tillage impact on soil water by Khan *et al*. (2014) showed that one pass of mouldboard plough + rotavator significantly increased soil moisture compared to four and two passes of cultivator. Ampofo (2006) suggested that some amount of soil compaction is required to increase soil water content. Tillage practices that increased surface roughness and created large macropores eventually increased water intake and storage (Sornpoon and Jayasuriya, 2013). Dam *et al*. (2005) and Kumar *et al*. (2012), however reported that no-till systems retained significantly higher soil moisture than conventional tillage systems. The differences in soil pore size and distribution were among the reasons assigned.

It has also been argued that the influence of tillage on soil water retention changes with change in water pressure. At 0 kPa, Bescansa *et al*. (2006), showed that conventional tillage system retained 13 % more water than no-till. However, at -33 kPa, water content of no-till system was 11 % higher than conventional tillage system. This may explain the observation of Olaoye (2002) who reported that the significant differences in soil moisture content among tillage practices recorded at planting disappeared by crop harvest.

2.3.5 Effect of tillage on soil porosity

Soil porosity describes the proportion of pore space in the total soil volume (Eluozo, 2013). Soil porosity ranges between 0. 3 to 0.7 depending on the size, shape, arrangement and distribution of soil particles as well as aggregation (Nimmo, 2004).

Soil porosity, affects the amount of soil water, gas exchange, fluid transport, evaporation, and root growth, etc. (Mulumba and Lal, 2008; Devine *et al*., 2014). Soil porosity changes with bulk density, penetration resistance, soil organic matter and specific surface area of soil aggregates (Hugar and Soraganvi, 2014).

According to Jabro *et al*. (2011), keeping permanent traffic paths significantly increased total porosity in strip tillage compared to conventional tillage which may be prone to random trafficking. Saha *et al*. (2010) reported that reduced soil disturbance in no-till system contributed to increased macroporosity through creation of biopores and higher soil organic matter content. However, Sessiz *et al*. (2010) and Alam *et al*. (2014) found no significant differences in total porosity of no-till, reduced tillage and conventional tillage systems.

2.3.6 Effect of tillage on soil aggregation and aggregate stability

Soil aggregation involves the binding together of finer and smaller easily transportable and dispersed soil aggregates into large, stable and well-structured forms by clay, soil organic matter, microbial biomass, and glomalin soil related protein (Mulumba and Lal, 2008; Zhang *et al*., 2012). Soil aggregation is important because, it promotes soil water infiltration, improve soil fertility, reduces soil susceptibility to erosion and enhances soil-atmosphere gaseous exchange (Causarano *et al*., 2008). Soil aggregation could be enhanced by crop production practices which increase addition of organic materials but decrease organic matter mineralization (Wagner *et al*., 2007).

The impact of tillage on soil aggregation and soil aggregates have been studied extensively. Ghuman and Sur (2001) observed that conventional compared with minimum tillage practices were not statistically different in their influence on soil aggregates. Similarly, Causarano *et al*. (2008) reported no significant differences in the dry mean weight diameter of soil aggregates among the tillage systems compared. However, significant differences were observed in wet mean weight diameter. Their results showed that soil from conventionally tilled systems easily slaked in water and increased the fraction of finer microaggregates than conservation tillage practice.

Ngetich *et al*. (2008) and Zhang *et al*. (2012) observed a significantly lower mean weight diameter under conventional tillage compared to no-till and minimum tillage. This could mean that conventional tillage increased finer soil aggregates. Devine *et al*. (2014) reported that the proportion of finer soil aggregates (< 53 μm) in conventionally tilled systems was higher compared to no-till systems.

Higher stability of soil aggregates in no-till and minimum tillage systems could be attributed to reduced soil disturbance which leaves soil binding agents undisrupted (Al-Kaisi *et al*., 2005), promotion of fungal growth and proliferation of fungal hyphae, increased soil organic matter (especially the particulate fraction) and increased aggregation .

2.4 Effect of tillage on soil chemical properties

2.4.1 Effect of tillage on soil organic matter

Soil organic matter is a component of the soil derived from flora and fauna, their secretions and residues (Kolář *et al*., 2009). Soil organic matter regulates physical, chemical and biological properties and processes (Burgess *et al*., 1996; Chen and Yang, 2013). Tillage is one of the crop production practices used in the management of soil organic matter (Six *et al*., 2002). Tillage, depending on its intensity, may expose physically protected soil organic matter to oxidation, decrease the concentration of soil organic matter, and predispose soil organic matter to fluctuating temperature and water loss (Balesdent *et al*., 2000).

Wright *et al*. (2007) reported that soil organic carbon content was stratified and significantly higher in the top 0 – 5 cm in both tillage systems studied though no-till was statistically superior to conventional tillage. Tillage enhances soil aeration and aerobic activities which decrease soil organic matter content (Dormaar and Carefoot, 1996; Oorts *et al*., 2007). Microbial activity and primary plant production are two main biological processes regulating additions and removal of soil organic matter (Six *et al*., 2002).

Soil microbes contribute to the accumulation, decomposition of organic matter and build-up of organic carbon. Curaqueo *et al*. (2010) showed that growth in total length of active mycorrhiza hyphae was 2.1 % more in no-till than conventional tillage. The fungi lives in symbiotic relation with plant roots and aids in water and nutrient uptake, stabilizes organic matter, aggregates soil particles. Conversely, tilling increased soil aeration, and doubled the population of radiation, U.V light and dessication resistant aerobic bacteria which mineralize stored carbon (Dorr de Quadros *et al*., 2012).

Hou *et al*. (2012) compared the impact of subsoiling-no-till-subsoiling, no-tillsubsoiling-no-till and continuous conventional tillage on soil organic carbon and reported that alternating tillage increased soil organic carbon content because of reduced intensity and frequency of soil disturbance. This might have decreased soil mechanical impedance and promoted root growth and development (Adeleye *et al*., 2011). Plant roots tend to replenish soil organic matter through rapid mineralization especially in the savannas than aboveground biomass which may decompose rather slowly (Dormaar and Carefoot, 1996).

2.4.2 Effect of tillage on particulate organic matter

Particulate organic matter (POM) represents the pool of soil organic matter which is neither undecomposed nor well decomposed (Luce *et al*., 2013). It is intermediate within the soil organic matter continuum and found in soil aggregates 0.25 mm and 0.053 mm (Handayani *et al*., 2009). It is mainly added to the soil by plant roots and it is known to be very dynamic and/or labile, thus more sensitive to management effect than total soil organic matter (Pikul *et al*., 2007). Mao *et al*. (2011) described the separation of particulate organic matter in two sieving processes, first by using 0.053 µm sieve and subsequently through 0.25 mm sieve. Particulate organic matter represents about 10 – 20 % of soil organic matter in wet and warm tropical and subtropical regions (Bayer *et al*., 2002 cited by Yang *et al*., 2009).

The report of Gajda (2010) and Gajda and Przewłoka (2012) showed significantly higher particulate organic matter in conservation than conventional tillage system. The authors also observed that particulate organic matter declined with increasing soil depth. Higher return of crop residues resulting in higher concentration of particulate matter on the top than subsoil could cause the variation of particulate matter with depth (Johnson *et al*., 2013). Also, reduced soil disturbance encourage slow mineralization of carbon because of decreased population of aerobic enzymes, and increased soil stability (Liebig *et al*., 2004). This is supported by findings of Causarano *et al*. (2008) which indicated that the protection and accumulation of particulate organic matter is enhanced in undisturbed than disturbed systems.

Mikha *et al*. (2006) observed quantitatively higher particulate organic matter in no-till than conventional tillage. They indicated that variation in soil variables such as soil temperature, bulk density and moisture content could explain the difference observed.

Lower particulate matter in conventional tillage systems have been explained by the rapid decomposition of added organic matter because of enhanced aeration and disaggregation of particles that protect soil organic matter (Dou *et al*., 2008).

Meanwhile, Balesdent *et al*. (2000) showed that tillage enhanced the contact between free particulate organic matter and soil mineral, thus increased the incorporation of plant derived matter. The incorporation of new carbon into free microaggregates for protection is very essential in carbon sequestration (Six *et al*., 2000; Tematio, 2011).

2.4.3 Effect of tillage on extractable organic matter

Extractable organic matter is the fraction of soil organic matter soluble in soil water (Hamkalo and Bedernichek, 2014). It is labile, spatial and temporal in nature (Ghani *et al*., 2003). Because of its solubility, extractable organic matter could be leached, adsorbed, desorbed and may contaminate groundwater (van Kessel *et al*., 2002). This makes it an important variable in both agriculture and environmental management. It is also called dissolved organic matter or soluble organic matter (Camino-Serrano *et al*., 2014). It could be sampled *in situ* with lysimeters, suction cups or piezometers

(van Kessel *et al*., 2002; Kolka *et al*., 2008; Jones *et al*., 2014). However, extractable or dissolved organic matter has also been obtained by leaching of soil with salt solution or any other extractant (including rainwater) (Ros *et al*., 2009).

Zhu *et al*. (2014) indicated that irrespective of tillage, dissolved organic carbon decreased with soil depth with no observable differences except in the 14 – 21 cm. The authors however indicated that the concentration of dissolved organic carbon could increase in undisturbed systems (no-tillage) because of the accumulation of soil organic matter. Lv and Liang (2012) reported significantly higher dissolved organic carbon at 60 cm soil depth (16.01 mg kg^{-1}) than the top 20 cm (14.57 mg kg^{-1}). In another report, dissolved organic carbon at the top 0 – 5 cm soil depth was significantly higher in no-till than conventional tillage (Wright *et al*., 2007). Conventional tillage breaks soil aggregates to liberate tied-up soil organic carbon through microbial attack and increased oxidation (Mohammadi, 2011). Therefore, decrease in soil organic matter may reduce the concentration of dissolved organic carbon in solution. Zhu *et al*. (2014) and Wright *et al*. (2007) reported that 75 % and 95 % respectively change in soil organic matter could result in change in dissolved organic carbon.

Notwithstanding, Jones *et al*. (2014) explained that dissolved organic carbon may not be sensitive enough to separate anthropogenic perturbations because of its wide variation especially among soils. Camino-Serrano *et al*. (2014) found that when about 16 soil types were assessed, Histosols showed significantly higher dissolved organic carbon content above half of the soil types, and no difference was subsequently noted amongst the other 15 soil types. Also, change in soil acidity affects the adsorption and desorption of dissolved organic carbon. Therefore higher concentrations of dissolved organic carbon were observed in soil's with low pH (5.47 – 5.80) (Undurraga *et al*., 2009).

2.4.4 Effect of tillage on mineralizable organic carbon

Mineralizable carbon is an estimate of the size of easily decomposable labile organic carbon pool (Spiegel *et al*., 2007). Mineralization of the labile carbon pool is measured by the carbon dioxide (CO_2) evolved from microbial oxidation of organic compounds (Liu *et al*., 2006). Tillage systems with higher concentration of soil organic carbon tend to emit higher amounts of CO_2 (Dou *et al*., 2008). However, rapid mineralization of soil organic carbon may decrease soil carbon sequestration if the amount and time of carbon input return is lesser than the rate of mineralization (Chen *et al*., 2014b) whilst slower mineralization of soil organic carbon may result in increased organic carbon sequestration (Al-Kaisi *et al*., 2005).

Temporal and spatial variability in tillage impact on mineralizable organic carbon have been reported. Gajda and Przewłoka (2012) reported significantly higher CO_2 release from reduced tillage and direct seeding systems than conventional tillage. However, Mulvaney *et al*. (2010), observed significantly higher CO_2 evolution in conventionally tilled fields than in conservation tillage. Jacobs *et al*. (2010) however reported significantly higher CO_2 from the top 0 – 5 cm soil depth of minimum tillage practice than conventional tillage. In the 10 – 20 cm depth, the reverse was observed.

2.4.5 Effect of tillage on maize and cowpea growth and yield

2.4.5.1 Maize (*Zea mays*)

Maize covers about 30 – 40 % of cropping area in Ghana (CSIR-SARI, 2013; MoFA, 2013). It is a major source of income for farmers and it accounts for 55 % of the daily calories requirement (Smale *et al*., 2011; Adu *et al*., 2014). Therefore, appropriate tillage practices that increase maize grain and stover yield are important for livelihood support. However, diverse accounts of tillage impact on maize growth and yield have been provided.

Scopel *et al*. (2005), Kombiok *et al*. (2006) and Kihara *et al*., (2011) indicated that conventional tillage systems (mouldboard plough, traditional bullock plough and disc plough and harrow) significantly increased maize growth and yield than no-till. Contrarily, Rockstróm *et al*. (2009) reported higher maize growth and yield under conservation tillage than conventional tillage. Ngwira *et al*. (2014) however noted no observable differences in tillage impact on maize growth and yield.

Delayed seed emergence and wide variability in plant growth (Videnović *et al*., 2011), high soil moisture content (Rusinamhodzi *et al*., 2011), seasonal variation (Wang *et al*., 2009), water use efficiency (Saha *et al*., 2010), variability in plant root density (Himmelbauer *et al*., 2012), as well as planting density (Tittonell *et al*., 2005) are among the factors that separate tillage impact on plant growth and yield.

2.4.5.2 Cowpea (*Vigna unguiculata* (L) Walp)

The grain legume is considered very important because of its economic and nutritional values. It has been estimated that western and central Africa produce between 75 %

(Anele *et al*., 2011) and 60 % of the world's cowpea (Adigun *et al*., 2014). In Ghana, 1,727,000 ha is cultivated with cowpea and total grain yield presently stands at 223 253 MT (MoFA, 2013). This crop is however delicate and may fail due to unfavourable crop production practices. Favourable soil condition for moisture storage, root development and reduced competition with weed significantly increase cowpea growth and yield (Qasem and Biftu, 2010).

According to Olaoye (2002), disc harrow and no-till significantly increased cowpea grain yield compared to disc plough harrow. Aikins and Afuakwa (2008) observed that the highest cowpea seedling emergence in the disc harrow plots contributed to the highest grain yield. Similarly, Polthanee and Wannapat (2000) indicated that grain yield of cowpea was numerically higher in conventional tillage than no-till practice.

Additionally, Aikins and Afuakwa (2010) observed that dry matter yield of cowpea was comparable in plough-harrow, harrow, and plough but was significantly higher than in no-till. The same study showed that the number of pods per plant was also significantly higher in plough-harrow than no-till.

2.5 Crop rotation

2.5.1 Definitions of crop rotation

Crop rotation is the cultivation of different crop species in a sequential pattern on the same land (Ball *et al*., 2005). Reeves (1994) defined crop rotation as a systematic and recurrent sequence of crops grown over a number of cropping seasons. Also, Florentín *et al*. (2010) described crop rotation as the cultivation of crops of different values, uses and purpose, with similar or different characteristics, and in predetermined manner in successive years. NRCS (2011) also defined crop rotation as growing crops in planned sequence on the same field. These definitions embody the crop rotation practice considered in this study.

2.5.2 The basic principles of crop rotation

Crop rotation is based on three basic principles (FAO, 2012). These are;

a. Crop rotation is better than monocropping even when crops in rotation are from the same family.

b. The most efficient rotations are those that include legume.

c. Crop rotation alone is not enough to maintain stable productivity for many years. There is the need for addition of external inputs.

2.5.3 Functions and benefits of crop rotation

Crop rotation increases soil organic matter content. Gregorich *et al*. (2001) observed that crop rotation increased soil organic matter content more than addition of mineral fertilizer. It regulates soil surface condition through roots and residue additions. Liebig *et al*. (2014) reported that crop rotation especially with diverse crops significantly reduced soil bulk density and increased water infiltration.

It has also been used in soil temperature regulation through its influence on surface insolation, surface albedo, and evaporation. For instance, Larney *et al*. (2003) reported that wheat-canola recorded lower soil temperature than wheat-fallow system. It has also been used in soil water management. For example Tripathi *et al*. (2005) and Singh and Kaur (2012) indicated that rotation enhances soil water storage by alternating crops with different water requirements.

Crop rotation has been used in soil erosion management. Rotation of grass-grain crops reduced soil loss on 2^o and 10^o slope by 75 – 80 % (Jankauskas *et al*., 2004). In addition to the above, rotation, enhances production system resilience to climatic fluctuations (Gaudin *et al*., 2015), reduces the incidence of pests and diseases (Feizabady, 2013), increases soil fertility, microbial diversity, and crop yield (Ayoubi *et al*., 2008). It provides farmers the opportunity to cultivate diverse crops in sequence based on profitability, household needs, marketability and water availability (Gill and Brar, 2005).

2.6 Effect of crop rotation on soil physical and hydrological properties

2.6.1 Effect of crop rotation on soil structure

Crop rotation systems have been used in the management of soil compaction, a major challenge to soil structural stability. Grant and Lafond (1993) reported a decline in soil compaction under rotation. The authors explained that nitrogen from legumes included in the rotation increased microbial population, decomposition of organic matter, enhanced soil aggregation and reduced compaction. Increase in soil microbial diversity under rotation was confirmed by Hilton *et al*. (2013) and soil microbes increase soil aggregation by enmeshing soil particles (Handayani *et al*., 2009).

Crop rotation, especially including diversity of crops, tends to increase soil surface residue which protects the soil from erosion (Krupinsky *et al*., 2007). Fattet *et al*. (2011) noted that the diversity of plant roots enhanced the stabilization of soil particles and increased the energy required to break soil aggregates. The diversity in the source of plant carbon may increase soil organic matter content and soil structural stability. Gregorich *et al*. (2001) reported that total soil carbon was 13 % higher in maizelegume rotation than continuous maize notwithstanding the higher biomass carbon returned to the soil by continuous maize. Similarly, soil organic matter was significantly higher in soybean-maize rotation than soybean and continuous cowpea (Perez-Brandan *et al*., 2014).

2.6.1.1 Effect of crop rotation on soil bulk density

Crop rotation affects soil bulk density through the additions of crop residues, root turnover and rhizodepositions (Andrews, 2006; Six *et al*., 2002). Additions of organic materials differs with crop types, sequence of crops, and number of crops in sequence (Malhi *et al*., 2008). Halabuk (2006) indicated that the variability in root weight of arable plants explained 52 % of change in soil bulk density. In the meantime, microbial decomposition of organic matter enhances the coagulation of soil particles into stable aggregates and reduces soil bulk density (Aziz *et al*., 2011).

Grant and Lafond (1993) showed that rotations that involved legume decreased soil bulk density by 5 % and 3 % than those that involved fallow and cereal monoculture respectively. However, lower soil bulk density was observed in continuous maize than maize-soybean rotation (Perez-Brandan *et al*., 2014). On the other hand, Celik (2011) reported no differences in soil bulk density under cereal-cereal and cereal-legume rotation. Rotations that increase addition of soil organic matter may decrease soil bulk density (Kurothe *et al*., 2014).

2.6.1.2 Effect of crop rotation on penetration resistance

Gaudin *et al*. (2015) asserted that crop diversification increased soil structural stability and reduced resistance to root penetration. Organic matter from residues added by aboveground and belowground biomass and exudates from microbial decomposition are very active in soil aggregation (Aziz *et al*., 2011). Froese (2004) indicated that penetration resistance decreased as soil organic matter increased. However, high soil organic matter content in well-structured soils when dried, could trigger increase in penetration resistance (Lampurlane´s and Cantero-Martı´nez, 2003). Landsberg *et al*. (2003) indicated that soils high in clay and organic matter tend to shrink when dry resulting in increased resistance to penetration. The addition of 8 Mg ha^{-1} of chicken manure increased penetration resistance by 1.7 kPa in wet season and 5.6 kPa in dry season (Thierfelder *et al*., 2004).

Motschenbacher *et al*. (2011) reported that the combination of different cereals in rotation may increase or decrease penetration resistance because of differences in the amount of added organic matter. On the other hand, Moraru and Rusu (2011) indicated that penetration resistance was not significantly different in the 3 years of legumecereal rotation. Also, Karuma *et al*. (2014) observed no differences in penetration resistance of continuous maize and continuous cowpea.

2.6.1.3 Effect of crop rotation on saturated hydraulic conductivity

Compacted soils generate runoff losses shortly after rain commences because of high bulk density. According to Feng *et al*. (2011), bulk density explained 49 % change in saturated hydraulic conductivity. High bulk densities increase the tendency for structural porosity collapse with a consequential reduction in saturated hydraulic conductivity (Costa *et al*., 2015).

Crop rotation influences vegetation type, root residues and exudates. These contribute to surface cover, stabilization of soil aggregates and preservation of water conducting pores (Khaledian *et al*., 2013). Jarvis *et al*. (2013) indicated that saturated hydraulic conductivity of an arable crop field was 2 – 3 times lower than natural vegetation, perennial agriculture and forests systems. Therefore, the appropriate combination of crops in rotation will reduce soil erosion, loss of soil organic matter and increase saturated hydraulic conductivity (Roose and Barthes, 2001). Jankauskas *et al*. (2004) reported that soil loss was significantly higher in field crop than fallow grass-grain rotations. The grass-grain rotations reduced soil loss by about 80 % above that of field crops. Additionally, Jadczyszyn and Niedÿwiecki (2005) explained that soil loss accounted for 47.7 % of variability in saturated hydraulic conductivity.

Bhattacharyya *et al*. (2006) reported a significantly lower saturated hydraulic conductivity in legume-cereal rotation than legume-legume rotation. From their study, Blanco-Canqui *et al.* (2004) also showed that soybean increased saturated hydraulic conductivity by 1.6 times more despite the higher amount of residue returned from maize. This may be explained by the higher residue quality of soybean, and higher decomposition rate (Bhattacharyya *et al*., 2006; Eusufzai and Fujii, 2012).

2.6.2 Effect of crop rotation on infiltration

The transmission of water into the soil depends on soil macropores (structural porosity) (Obalum *et al*., 2011). Water infiltration is important because, it affects water availability for plant growth, nutrient cycling, solute transport, regulation of soil and plant temperature, and wetting and drying cycles (Sauwa *et al*., 2013b). Crops and crop types influence water infiltration through their impact on the distribution and continuity of macropores, soil aggregation and protection of soil surface.

Bharati *et al*. (2002) observed a significantly higher cumulative infiltration under soybean-corn rotation than continuously grazed fields. In a related study, infiltration was 24.8 % higher on cassava-legume systems but not statistically different from continuous cassava (Thierfelder *et al*., 2004). Inclusion of legume (*Centrosema macrocarpum)* in rotation enhance soil organic matter content and stabilization of soil aggregates (Ayoubi *et al*., 2008).

2.6.3 Effect of crop rotation on total porosity

Soil porosity is a composition of macropores and mesopores (which make the structural porosity) and micropores (textural porosity) (Costa *et al*., 2015). Soil porosity is important because it controls soil water inflow and outflow, controls gas exchange between the soil and the atmosphere (Osunbitan *et al*., 2005). These processes have direct impact on soil fertility, productivity and plant growth (Jin *et al*.,

2009). Reports on the contribution of crop rotation to soil porosity are contradictory. This could be explained by the different crops and sequence of crops in rotation, cropping season, and soil type.

Aziz *et al*. (2011) reported that the effect of crop rotation on total porosity was similar with only marginal differences observed. However, Vyas *et al*. (2013) reported that rotations including maize recorded higher total porosity than with wheat. In a similar study, total porosity was significantly higher in systems cultivated with maize after wheat than systems planted with wheat after maize (Fuentes *et al*., 2011). Moraru and Rusu (2011) explained that water stability of soil aggregates decreased when maize followed wheat in rotation, and the stability of soil aggregates is positively related to soil porosity (Shaver, 2010).

2.6.4 Effect of crop rotation on soil water retention

Crops affect soil water retention through their above and below ground biomass. Above ground biomass (from leaves, branches and stems) physically shades and cools soil surface from water loss to evaporation and adds to soil organic matter which increases soil water retention (Shafi *et al*., 2010). Calegari *et al*. (2010) opined that the impact of belowground plant biomass on soil characteristics is higher than the aboveground. Root growth and extension, affect soil water retention by influencing aggregation of soil particles, hydrological cycle (by transpiration), soil macroporosity, and through rhizodeposition (Feng *et al*., 2011).

Soybean, maize and wheat were arranged in four patterns for rotation study (Moraru and Rusu, 2011). The behaviour of soil water retention was variable from planting, through vegetative development to harvest. The study showed that cultivation of soybean conserved soil water best than wheat and maize (Moraru and Rusu, 2011). Nevertheless, Bhattacharyya *et al*. (2006) indicated that soybean did not make any difference in water retained than wheat.

Also, Feng *et al*. (2011) observed that the efficiency of rotation systems in increasing soil water retention tended to be higher in dry than wet periods. Grant and Lafond (1993) also reported that crop rotation including fallow retained higher soil moisture than without fallow. However, Calegari *et al*. (2010) asserted that crop rotation including fallow reduced soil moisture.

The overview of literature appears to suggest that crop rotation has marginal impact on soil water retention. This may confirm the comments of Thierfelder *et al*. (2012) that tillage and residue management strongly impact soil water retention than crop rotation.

However, Vyas *et al*. (2013) indicated that the impact of crop rotation on water filled pores was comparable to tillage.

2.6.5 Effect of crop rotation on soil aggregation and aggregate stability

Crop rotation increases the diversity of plant matter (leaves, stems, and roots) and soil fauna (Gaudin *et al*., 2015). Fattet *et al*. (2011) observed that variation in vegetation type, root length density, and soil organic carbon content explained differences in soil aggregate stability.

Sharratt *et al*. (2006) noted that under stable soil conditions, large soil aggregates were formed which enhanced soil resistance to erosive agents. Therefore, rotations involving grasses reduced soil surface disturbance through the protective cover of the grass vegetation while their fine roots entangled and bound soil particles into aggregates (Jankauskas *et al*., 2004).

However, Aziz *et al*. (2011) reported that compared to the initial, corn-soybean rotation significantly reduced soil aggregates stability, continuous corn was comparable with the initial, and corn-soybean-wheat was significantly higher than the initial. The authors suggested that quality and quantity of added organic matter accounted for the observed differences.

2.7 Effect of crop rotation on soil chemical properties

2.7.1 Effect of crop rotation on soil organic matter

Crop diversification contributes different root systems and plant biomass to the soil organic matter pool (Liu *et al*., 2006). Motta *et al*. (2007) and Shrestha *et al*. (2013) reported significantly higher soil organic carbon in extensive and diversified than systems including fallow. High carbon input could account for the increased soil organic carbon content in intensively cultivated systems (Moulin *et al*., 2011).

However, other studies observed higher soil organic carbon in continuous fallow systems than legume-millet rotation (Bationo and Ntare, 2000). Sparrow *et al*. (2006) explained that continuous fallow reduced soil disturbance and abundance of aerobic bacteria required for organic matter mineralization. Gregorich *et al*. (2001) reported soil organic carbon to be significantly higher in maize rotation system than continuous maize system.

Malhi *et al*. (2008) and Martinrueda *et al*. (2007) however observed that crop diversification did not influence soil organic carbon content. This according to Sainju *et al*. (1998) could be due to similarity in nutrient composition of added plant matter and the amount of carbon input.

2.7.2 Effect of crop rotation on particulate organic matter

Particulate organic matter is the readily decomposable organic matter associated with the sand size fraction of soil particles (Saljnikov and Cakmak, 2013). On the basis of density, particulate organic matter is classified as light fraction organic matter (1.4 – 2.2 g cm^{-3}) (Jia *et al*., 2006) and according to aggregate size, it is fine and coarse (53 – 250 µm) (Pulleman *et al*., 2005; Yang *et al*., 2009). Its contribution to soil organic matter has been variously reported as 16 % – 52.4 % in Qiu *et al*. (2010), 50 % - 63 % in Beedy *et al*. (2010) and 29 % - 48 % (Motta *et al*., 2007).

Beedy *et al*. (2010) observed a significant influence of cropping system on the concentration of particulate organic matter. Their study showed that the inclusion of *Gliricidia* increased the contribution of particulate organic matter to total soil organic matter by 13 % above monoculture whilst (Wang and Sainju, 2014) indicated significant increase in particulate organic matter under wheat than pea. The quantity and quality of crop residues added by cropping systems have been used in explaining the differences in the concentration of particulate organic matter (Dou *et al*., 2008; Liebig *et al*., 2004).

Mao *et al*. (2011) found that the influence of crop rotation on particulate organic matter is subject to clay content of the soil. Clay is important in the protection and stabilization of the organic matter from microbial attack and therefore results in higher concentration of soil organic carbon than larger soil particle sizes as reported by Chivenge *et al*. (2007).

2.7.3 Effect of crop rotation on extractable organic matter

The proportion of soluble soil organic matter is influenced by the return and decomposition of crop residues, root exudates, and soil faunal activity (Lv and Liang, 2012). The concentration of dissolved organic carbon in soil is driven by the concentration of NH_4^+, C:N, Al^{3+} and Fe^{3+} in solution and on soil colloidal surfaces (Camino-Serrano *et al*., 2014). In the topsoil (0 – 20 cm), NH_4^+ and Al^{3+} mainly regulate the concentration of dissolved organic carbon and for 40 – 80 cm, the main controlling variable is dry season precipitation (Camino-Serrano *et al*., 2014).
Undurraga *et al*. (2009) reported a significantly higher impact of cropping intensity on the concentration of dissolved organic carbon. However, the pattern of their results between cropping systems and soil depths was not consistent. This accords with the observation of Jones *et al*. (2014) that dissolved organic carbon has a wide spatial and temporal variability which masks real differences.

However, Xue *et al*. (2013) reported significant differences in dissolved organic carbon among vegetation types in the order of native forest > revegetated field > cropped hillslope. They explained that revegetation increased below ground biomass, nutrient turnover and microbial related carbohydrate. Thus, the dissolved organic carbon has been found to be strongly correlated with microbial biomass and activities (Wang and Wang, 2011).

2.7.4 Effect of crop rotation on mineralizable organic carbon

Crop rotation affects soil respiration through the amount and diversity of organic resources added from root biomass and exudates, aboveground biomass, and surface temperature regulation (Lupwayi *et al*., 2004; Bonsu and Asibuo, 2013). Higher availability of rhizodepositions was found to increase the size of unprotected labile organic carbon and the mineralizable organic carbon (Patra *et al*., 2010).

Also, maize-mucuna rotation compared to other cereal-legume and cereal-grass rotations produced significantly higher mineralizable soil organic carbon (Adiku *et al*., 2008). In that same report, significantly lower microbially oxidizable organic carbon was observed under maize-pea and maize-cowpea rotations compared to nonlegume systems. This may be due to the fact that rotations including legumes reduce soil carbon-nitrogen ratio and increase soil carbon mineralization which could lead to carbon loss and decrease organic matter content (Wang and Sainju, 2014).

2.8 Effect of crop rotation on maize and cowpea growth and yield

2.8.1 Maize

Crop diversification has many known beneficial effects on plant growth and yield. Some of these benefits include; increased soil water content, higher quantity and quality of organic residues, availability of plant nutrients, and sustained productivity

(Adu *et al*., 2014). However, the intensity of crop diversification, the crop types and sequence have varied impacts on crop growth and yield.

Ennin *et al*. (2004) reported maize yield increase of 15 % when preceded by cowpea than in continuous maize. Also, Wang *et al*. (2008) indicated that maize growth and yield was 3.95 % higher in previous alfalfa plots than in continuous maize. Maize growth and yield in maize-grass chemically fertilized systems was significantly higher compared to the means of maize-legume (cowpea, mucuna and pigeon pea) and maizegrass systems in four years of rotation (Adiku *et al*., 2009). Adjei-Nsiah (2012) also reported higher maize growth and yield in cowpea-maize-cowpea rotation than continuous maize.

2.8.2 Cowpea

The inclusion of cowpea in rotation with cereals amongst other crops is beneficial to sustainable land development (Adomako *et al*., 2013). Rotations with legume could minimize depletion of soil N and soil organic matter and reduce incidence of weeds and pests (CSIR-SARI, 2013; Rusinamhodzi, 2015). Rotations with legume also return higher crop residue to the soil. Cowpea-maize rotation returned a numerically higher total dry matter and 17 kg N ha^{-1} more nitrogen than continuous maize (Adjei-Nsiah, 2012).

However, the rotational benefit to cowpea growth and yield has been scarcely assessed. Hence, not many reports are available on the rotational effect to cowpea growth and yield. Notwithstanding, Bationo and Ntare (2000) reported that cowpea stover yield was superior in millet-cowpea rotation than continuous cowpea and the difference grew wider with addition of nitrogen nutrient. On the other hand, Bagayoko *et al*. (1996) observed successive decline in grain yield of cowpea in rotation with pearl millet. In the meantime, Ndiaye *et al*. (2008) noted that cowpea-millet systems enhanced the accumulation of *M. phaseolina*, a causal agent of Charcoal rot in cowpea resulting in yield decline.

2.9 Crop residues

Crop residues are plant materials that remain above ground and below ground (Dormaar and Carefoot, 1996). Crop residues store plant nutrients and are able to release these nutrients during decomposition for plant use (Blanco-Canqui and Lal, 2009). However, nutrient release of crop residue is dependent on its nutrient content besides soil and climatic influences (Bot and Benites, 2005). Crop residues used as mulch protect the soil against erosive forces; reduce soil surface compaction and evaporation; increase soil water retention and soil organic matter (Klocke *et al*., 2009). But, in most cropping systems in sub-Saharan Africa, competing uses of crop residues (fuel, feed and housing) limits their availability and use in cropping fields (Valbuena *et al*., 2012).

2.9.1 Mulching

Mulching is the retention of any material on the soil with the purpose to protect the soil surface against erosive agents, while conserving soil water. Materials used for mulching include live plants (cover crops) (Reddy, 2001), crops residue and plastic film (Mochiah and Baidoo, 2012).

2.9.2 Mulch application

Mulch application varies among cropping systems. The soil surface beneath the mulch is undisturbed in direct seeding mulch-based cropping systems (DMS) or no-till with mulch (Scopel *et al*., 2005). Ogban *et al*. (2008) described two systems where first, mulch was spread on the soil surface before ploughing resulting in incorporation of the residues and secondly where mulch was spread after ploughing.

2.9.3 Mulching rate

In their study of maize stover effect on soil erosion, Scopel *et al*. (2005) reported that mulch rate between 1.5 Mg ha^{-1} – 4.5 Mg ha^{-1} were effective in protecting soil surface against runoff and erosion. In Mupangwa *et al*. (2012), maize stover applied at 4 Mg ha^{-1} significantly improved soil properties and grain yield and was not different from that applied at twice its rate. In eastern Ethiopia, Bekeko (2013) recommended the use of 8 Mg ha^{-1} of maize stover in coffee production. According to Ogban *et al*. (2008), Lal (1975) recommended a mulching rate of 4 – 6 Mg ha^{-1} as appropriate for soils in tropical regions.

2.9.4 Importance of mulching

Mulching protects soil surface from the direct impact of raindrop or wind (Chivenge *et al*., 2007). Soil particle detachment and transport, and surface sealing and crusting are thereby reduced in mulched systems (Ogban *et al*., 2008). It traps excess soil water from running on soil surface and allows more time for infiltration. Dadoun (1993) stated that crop residue holds mulch water about 3.8 times their dry weight. Scopel *et al*. (2005) has shown that on bare soil surface, more than 30 % of annual rainwater was lost whilst 1.5 Mg ha^{-1} maize stover mulch reduced runoff water by 28 % to 50 % in two years.

It increases soil water content by reducing evaporation. This is because residue water is evaporated in place of soil water (Basso *et al*., 2006). Mulching regulates soil temperature by insulating soil surface from absorption of radiant energy and by reflecting net radiation from the sun back to the atmosphere (Polthanee and Wannapat, 2000).

Mulching suppresses weed growth and reduces weed competition on crop fields. Naudin *et al*. (2010) showed that significantly lesser number of weeding was needed to maintain no-till with mulch compared to no mulch plots. Mulching has also been shown to reduce the incidence of pests and diseases without affecting the existence of natural enemies to pests in crop production. Live-mulch, straw mulch and plastic mulch significantly reduced aphids population in pepper compared to the control (Mochiah and Baidoo, 2012).

In spite of these benefits, mulching presents some challenges. These include inhibition of microbial acitivity by crop residue mulch containing tannis and phenolic compounds (Lahmar *et al*., 2012), allelopathy due to polyphenolic compounds

(Hulugalle and Weaver, 2005) and labour intensiveness (Bhardwaj and Sarolia, 2012).

2.10 Effect of mulch on soil physical and hydrological properties

2.10.1 Effect of mulch on soil structure

The impact of crop residue mulch on soil structure is manifested through its effect on soil physical, chemical and biological properties. Physically, crop residue mulch cushions soil surface from direct radiant energy, force of raindrop and wind (Zhang *et al*., 2007). Reduction in soil surface disturbance could increase aggregation and soil stability (Kihara *et al*., 2011). Also, mulch increases soil stability by reducing the frequency of dry and wet cycles (Flerchinger *et al*., 2003; Mupangwa *et al*., 2011).

Soil organic matter binds and stabilizes soil aggregates and increases soil structural stability. Hulugalle and Weaver (2005) reported that addition of crop residues with high carbon-nitrogen ratio increased soil organic matter content. However, Bescansa *et al*. (2006) showed that the influence of crop residue mulch soil organic matter on fine textured soil was marginal.

Additionally, beneficial soil microbes contribute to soil structural development by adding organic compounds through decomposition, and physically enmeshing soil particles with their hyphae. Microbial biomass, respiration and activities were observed to be higher under mulch compared to natural fallow (Rabary *et al*., 2008). Higher microbial activity under residue mulch is explained by temperature attenuations, higher moisture content and availability of plant material (Agbede *et al*., 2013).

2.10.2 Effect of mulch on soil compaction

The soil is compacted when the particles are disaggregated and pressed together resulting in reduction in pore space size distribution, higher bulk density, and penetration resistance (Rusinamhodzi *et al*., 2011). Soil compaction is enhanced by traffic, rain drop impact, weight of overlaying soil horizon, and particle consolidation (Leung and Meyer, 2004). The impact of compaction on soil could be restored with crop residue mulch through its influence on soil biological and physical processes (Logsdon and Karlen, 2004).

But, retaining crop residue mulch on compacted soil would not immediately reduce the state of compaction as in the use of tillage. Dao (1996) stated that crop residue mulch influenced soil compaction by enhancing soil water retention, root development and microbial activities. Meanwhile, Ess *et al*. (1998) reported that soil surface compaction was not transformed by the retention of 1.08 – 10.5 Mg ha^{-1} of crop residue mulch.

High soil compaction is unfavourable for sustainable soil management, crop growth and development. Yvan *et al*. (2012) explained that soil compaction reduced macropore abundance and continuity which accounted for 90 % decrease in

infiltration. High soil compaction limits rooting depth and plant access to soil water and nutrients resulting in declined growth and development (Wingeyer *et al*., 2015).

2.10.2.1 Effect of mulch on soil bulk density

Retaining wheat residues mulch resulted in significantly lower bulk density at 0 – 20 cm and 21 cm – 40 cm depth than without mulch (Khan *et al*., 2014). The significance of crop residue in reducing bulk density was also highlighted by Ghuman and Sur (2001) who compared mulched with no mulch systems on a sandy loam in northwestern Punjab and reported numerically lower values in favour of mulching.

Blanco-Canqui *et al*. (2006) worked on three soil types and observed that systems with no residues retained, recorded significantly higher bulk density but not at all times. The authors reported that some soils responded very slowly to residue additions because of their inherent properties (such as clay content) and hence required years of residue incorporation to ensure early response to mulching.

Increasing soil organic matter content may not always reduce soil bulk density. Blanco-Canqui *et al*. (2011) observed that soil organic carbon was significantly higher when soil surface was mulched with (sunn hemp and late maturing soybean residues) but this did not reduce soil bulk density. Meanwhile other studies (Bescansa *et al*.,

2006) observed higher bulk density in mulched fields.

2.10.2.2 Effect of mulch on penetration resistance

Soil resistance to penetration is increased when soil pores get sealed resulting in crust formation on bare soil surface (Zejun *et al*., 2002). Surface sealing and crusting increases the energy required by plants to emerge and to extend roots deep into the soil (Olaoye, 2002). Therefore agronomic practices that leave soil surface bare, increase surface slaking, run-off, and penetration resistance (Verhulst *et al*., 2011).

The study of Blanco-Canqui *et al*. (2006) showed that on three distinct soil types assessed, penetration resistance declined quadratically in response to increase in amount of corn residue retained. Also, Fuentes *et al*. (2009) observed that retaining residues mulch in no-till plots resulted in a numerically higher (12.8%) penetration resistance than incorporation in conventional tillage plots. Karlen *et al*. (1994) and Sornpoon and Jayasuriya (2013) found no significant differences in penetration resistance under double rate, normal rate and no residue applications.

2.10.2.3 Effect of mulch on saturated hydraulic conductivity

Saturated hydraulic conductivity measures the ability of the soil to transmit water (Halabuk, 2006). This soil parameter is important for the regulation of infiltration, surface runoff, drainage, and leaching (Bhattacharyya *et al*., 2006). Saturated hydraulic conductivity is dependent on the size and distribution of soil pores particularly, macropores formed by the burrowing action of earthworms and channels of old plant roots (Osunbitan *et al*., 2005).

It is very variable in space and time because of dynamic plant canopy, microbial activities, root growth and development and decomposition (Fasinmirin, 2003). Ajayi and Aruleba (2014) reported a significantly higher saturated hydraulic conductivity for mulched plots (115 cm h^{-1}) than no mulch. Furthermore, Scopel *et al*. (2005) attributed higher saturated hydraulic conductivity under mulch to increased soil organic matter, microbial activities and total porosity. However, Das *et al*. (2012) observed that saturated hydraulic conductivity decreased with time because of reduction in soil moisture content.

2.10.3 Effect of mulch on total porosity

Soil porosity is the proportion of the total soil volume occupied by pores (Nimmo, 2004). The protective layer provided by mulch on soil surface preserves surface pores from seals and crusts. Also, decomposition of crop residue mulch increase soil organic matter content, soil aggregation and structural porosity (Blanco-Canqui and Lal, 2009).

Compared to bare soil surface, Khan *et al*. (2014) reported a significantly higher total porosity in mulched soil. In addition, Mulumba and Lal (2008) reported that total porosity increased linearly with the amount of crop residue mulch retained. Likewise, Shaver (2010) indicated that the amount of crop residue mulch retained explained 70 % of the variability in total porosity. Klocke *et al*. (2009) also found residue mulch to increase the amount of soil moisture retained. Increased soil porosity increases soil aeration, infiltration, root growth and nutrient cycling (Ghuman and Sur, 2001; Chen *et al*., 2014a).

2.10.4 Effect of mulch on soil water content

Mulched soil surfaces reduce soil water loss by evaporation through interception of rainwater and radiant energy, restriction of surface runoff, and increased infiltration than bare soil surfaces (Flerchinger *et al*., 2003; Bhardwaj and Sarolia, 2012). Shaheen *et al*. (2010) observed that retention of 4 Mg ha^{-1} of wheat straw significantly increased soil water content throughout sorghum growth cycle. In essence, residue architecture (position and location), thickness, resistance to decomposition, and time of application (Sauer *et al*., 1996; Klocke *et al*., 2009; Myburgh, 2013; Sommer *et al*., 2014) are relevant to soil water retention.

Shen *et al*. (2012) studied the impact of three rates (0, 6 and 12 kg ha^{-1}) of winter wheat mulch on soil water storage, evapotranspiration and crop water use efficiency of maize. Results from their study showed that soil moisture content was significantly higher under mulched plots at tassel opening and silking. At maturity, numerically lower moisture was recorded in mulched plots. The authors explained that increase in leaf area index under mulched plots increased transpiration which resulted in decreased soil water content. Mulumba and Lal (2008) observed significantly higher volumetric water content at 16 Mg ha^{-1} mulch rate than 0 Mg ha^{-1} at saturation but no differences existed among mulch rates at high suction (1500 kPa).

2.10.5 Effect of mulch on infiltration

Bharati *et al*. (2002) and Adekalu *et al*. (2007) indicated that water infiltration is site specific and subject to slope, tillage, cropping practice and residue management. The absence of mulch on cultivated soil could cause surface sealing and crusting and reduce water infiltration (Le Bissonnais and Arrouays, 1997; Bhardwaj and Sarolia, 2012) whilst the presence of mulch could impove soil organic matter and burrowing activities of soil organisms (Agbede *et al*., 2013).

Blanco-Canqui and Lal (2009) stated that some soils e.g. silt loam and clayey soils may not show immediate change in infiltration when mulched. The presence of poorly drained subsoil beneath mulch, higher soil hydrophobic properties, lower evaporative rates and higher antecedent soil moisture were among the reasons stated for lower infiltration under mulch. Yuxia *et al*. (2001) indicated that mulch effect on time to ponding and steady state infiltration under wheeled and compacted soil surface was insignificant when compared to bare plots. Nevertheless, Ess *et al*. (1998) explained that the remains of plant roots on residue removed plots could sustain preferential noncapillary pores beyond that of residue covered plots even after five traffic passes.

2.10.6 Effect of mulch on soil aggregation

The binding and stabilization of soil into structural aggregates is facilitated mainly by soil organic matter obtained from plant residues, exudates from live and remains of plant roots and earthworm casts (Curaqueo *et al*., 2010). Also, fine roots, arbuscular mycorrhiza hyphae and clay also bind soil particles into aggregates (Oorts *et al*., 2007). The type of crop residue mulch, quantity applied, and quality of material affects mulch influence on soil aggregates (Blanco-Canqui and Lal, 2009). Additionally, Scopel *et al*. (2005) expressed that any small amount of crop residue mulch retained could effectively control soil surface characteristics.

Meanwhile, the stabilization of soil aggregates by organic matter increases resistance of soil aggregates to dispersion (Mulumba and Lal, 2008). Results of many studies show that crop residue mulch including; redclover (Gaudin *et al*., 2013), corn stover (Linden *et al*., 2000), wheat straw (Masciandaro *et al*., 2004), rice straw (Lal, 1998), soybean (Paul *et al*., 2013) unspecified grass vegetation (Mbah and Nneji, 2011) enhanced soil aggregation.

Also, crop residue mulch physically protect soil aggregates from disintegration and dispersion (Karlen *et al*., 1994; Balota *et al*., 2011). According to (Ogban *et al*., 2008), mulching increased erosion resistant water stable aggregates (> 0.5 mm) by more than

60 % . Similarly, Lichter *et al*. (2008) reported that retention of crop residue mulch significantly increased larger (> 2 mm) and small (0.25 – 2 mm) macroaggregates over microaggregates (< 0.25 mm) compared to residue incorporation systems.

2.11 Effect of mulch on soil chemical properties

2.11.1 Effect of mulch on soil organic matter

Crop residue mulch protects soil surface from fluctuations in water and temperature, and by that create favourable microclimate beneficial for enhancing the activities of soil microorganisms and invertebrates (Singh *et al*., 2011). These enhance the recycling of added residues and increase soil organic matter content (Khurshid *et al*., 2006; Handayani *et al*., 2009).

Mulch application rate, nutrient composition and soil characteristics may determine the impact of crop residue mulch on soil organic carbon (Pakdel *et al*., 2013). Also, differences in nutrient composition of mulch material may account for their influence on soil organic carbon content as suggested by the report of Agbede *et al*. (2013). The authors showed that mulching with crop residues of *Tithoni*a (carbon–nitrogen ratio of

7.8) significantly increased soil organic carbon content compared to that of *Chromoleana* (carbon-nitrogen ratio of 12.9).

Meanwhile, many studies (Mbah and Nneji, 2011; Ghimire *et al*., 2011) have shown increased soil organic carbon content with mulch than without. Additionally, Moulin *et al*. (2011) indicated that residues mulch increased soil organic carbon content above systems without mulch. Crop residue mulch improve soil surface and subsoil condition which favour the build-up of soil organic carbon (Bhardwaj and Sarolia, 2012).

2.11.2 Effect of mulch on particulate organic matter

Crop residue mulch quantity and quality may affect the concentration of particulate organic matter in the soil. Therefore, varied soil responses to applied mulch have been reported. Chivenge *et al*. (2007) reported an increase in macro-organic matter in mulched systems. The authors subsequently recommended the use of crop residue mulch but not reduced tillage for organic carbon build-up in sandy soils. Briedis *et al*. (2012) explained that mulching increased the accumulation of carbon input on the soil surface, thus increased particulate organic matter.

Tian *et al*. (2013) reported that wheat straw mulch significantly increased particulate organic matter than plastic mulch and traditional flooding. They explained that soil organic matter increased through decomposition of organic residues (plant and animal remains and secretions). The work of Johnson *et al*. (2013) seems to suggest that the concentration of particulate organic carbon is not entirely influenced by crop residue mulch retained. Their results showed fluctuations of particulate organic carbon among full, moderate and low amounts of crop residue mulch. Meanwhile, Wang and Sainju (2014) reported that neither residue incorporation nor mulching influenced particulate organic matter.

2.11.3 Effect of mulch on extractable organic matter

Application of mulch creates microclimate by gradually cooling the soil through reduced surface temperature (Sharratt *et al*., 2006), favourable for enhancing the activities of soil microorganisms. Balota *et al*. (2011) reported that accumulation of mulch on soil surface may increase the activities of *glycosidas*e because of the increased supply of easily decomposable organic substrates e.g. carbohydrate. Also, reduced surface runoff and soil loss and increased water infiltration enhance concentration of dissolved organic carbon (Adekalu *et al*., 2007).

Dissolved organic carbon was significantly higher under plastic film mulch in the top 0 – 5 cm soil depth compared to wheat straw and traditional flooding (Tian *et al*., 2013). They explained that the concentration of dissolved organic carbon declined with increased soil depth. Therefore, no apparent differences were observed at deeper soil layers. They further indicated that higher temperature under plastic film mulch could have stimulated microbial activity which enhanced liberation of dissolved organic carbon from soil organic carbon.

2.11.4 Effect of mulch on mineralizable carbon

Compared to no mulch systems, Larney *et al*. (2003) indicated that soil surface protection with crop residue mulch reduced insolation, surface temperature and minimized mineralization of soil organic carbon. According to Mulvaney *et al*. (2010), mulching reduced the decomposition of labile organic carbon (the main constituent of the mineralizable organic carbon). The findings of Larney *et al*. (2003) corroborated by Smith *et al*. (2012) indicated a significantly higher carbon mineralization in bare plots compared to mulched surfaces. Contrarily, Zhu *et al*. (2014) reported a significantly higher concentration of mineralizable organic carbon in residue mulch than no mulch.

Differences in mineralizable organic carbon have also been attributed to type, quantity and quality of mulch retained (Adiku *et al*., 2008). Alfalfa significantly increased carbon mineralization over wheat straw mulch in both cultivated and uncultivated soils (Raiesi, 2006). Inclusion of a legume in high carbon systems may decrease C/N ratio and increase the mineralization of stored carbon (Carsky *et al*., 2002).

2.12 Effect of mulch on maize and cowpea growth and yield

2.12.1 Maize

Crop residue mulch increases soil moisture content and enhances water availability for plant uptake and growth (Bekeko, 2013). Crop residue mulch enhances water infiltration and restricts evaporation of soil water (Shen *et al*., 2012). Through decomposition, crop residue mulch increases soil nutrients needed for plant productivity (Gotosa *et al*., 2011). However, variation in climate, soil type, residue amount and type may explain the contradictions in the impact of mulching on maize growth and yield (Linden *et al*., 2000).

The work of Najafinehad *et al*. (2007) showed that wheat residues mulch numerically increased maize growth and yield above residue burning. Mbah and Nneji (2011) also reported that mulching significantly increased maize grain yield. However, Mupangwa *et al*. (2011) explained that the retention of > 2 Mg ha^{-1} of maize residues mulch in their Matopos site, Zimbabwe decreased maize grain yield because of higher soil water content. Meanwhile, the retention of 15 Mg ha^{-1} of wheat straw mulch showed significantly higher maize grain yield over no mulch in Faisalabad, Pakistan (Khurshid *et al*., 2006).

Notwithstanding, evidence from Scopel *et al*. (2004) and Scopel *et al*. (2005) showed that irrespective of site, grain yield of maize increased with amount of residue mulch retained because of increased beneficial water loss through transpiration. But in some instances, highest growth and yield of maize have occurred in lower than moderate and full residue return plots (Johnson *et al*., 2013).

2.12.2 Cowpea

Crop residue mulch protect soil surface from direct environmental impact and increase soil organic matter and microbial activity through decomposition (Bajoriene *et al*., 2013). However, the effect of mulch on the soil and plant growth varies with mulch type, thickness, amount and quality (Rabary *et al*., 2008; Agbede *et al*., 2013).

Meanwhile, Ogban *et al*. (2008) reported significantly higher total root length and cowpea grain yield in undisturbed mulched system compared to systems that incorporated residues.

Lal (1998) indicated that cowpea grain yield was influenced by the amount of crop residue mulch retained. His results show lowest yield under zero mulch and highest yield under highest mulch retained. Nevertheless (Mbagwu, 1991) reported that at straw mulch rate of 4 Mg ha^{-1}, cowpea grain yield increased by 67 % above bare plot. Also, Awodun *et al*. (2007) showed that cowpea grain yield and yield components increased progressively with retention of *Gliricidia* residues mulch. Mupangwa *et al*. (2012) observed that cowpea grain yield at 10 Mg ha^{-1} mulch was numerically lower compared to 0 Mg ha^{-1}. They also observed that in cropping systems that retained higher soil moisture, cowpea grain yield at 0 Mg ha^{-1} increased significantly above 10 Mg ha^{-1}.

Nonetheless, Polthanee and Wannapat (2000) indicated that the retention of 2 Mg ha^{1} of rice straw significantly increased leaf area, top dry weight and grain yield of cowpea than no mulch. Despite the decline in nodule number, nodule fresh and dry weight in mulched system, Singh *et al*. (2011) reported that cowpea grain yield was significantly higher than in no mulch.

2.13 Summary of literature review

Information gathered from literature showed that the impact of tillage methods on soil properties was very diverse. Tillage practices that increased soil compaction were more likely to reduce infiltration and destabilize soil aggregates. Also, tillage practices that increased soil disturbance, soil aeration and aerobic microbes, recorded higher mineralization rates and decreased carbon stored over time. Meanwhile, improvement in soil properties by conservation tillage practices, did not always translate into increased maize or cowpea grain and stover yield. Of all the tillage practices evaluated, not many studies are available on tillage rotation.

The diversity of plant roots enhanced soil macropore formation, aggregates stabilization through increased soil organic matter content. Generally, reports on crop rotation effect on soil physical properties were scanty. Crop residue mulch protected soil surfaces, enhanced the stabilization of soil aggregates overtime, retained the movement of free water and allowed percolation at the expense of erosion. However, the positive impact of mulch is not immediately manifested when applied on compacted soil surfaces. Meanwhile, diversity in mulch type, amount, time of placement and quality were important factors influencing the effects of mulching. The observations noted from the literature review, formed part of the hypothesis and objectives of this study.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of study area

3.1.1 Location

The study was undertaken at the Agriculture Research Station (Figure 3.1) of Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST) located at Anwomaso ($6^{o}41'21.68''N$, $1^{o}30'53.97''W$) in the semi-deciduous forest zone of Ghana. The area is predominantly covered with grass mainly, *Panicum maximum* interspersed with trees and shrubs.

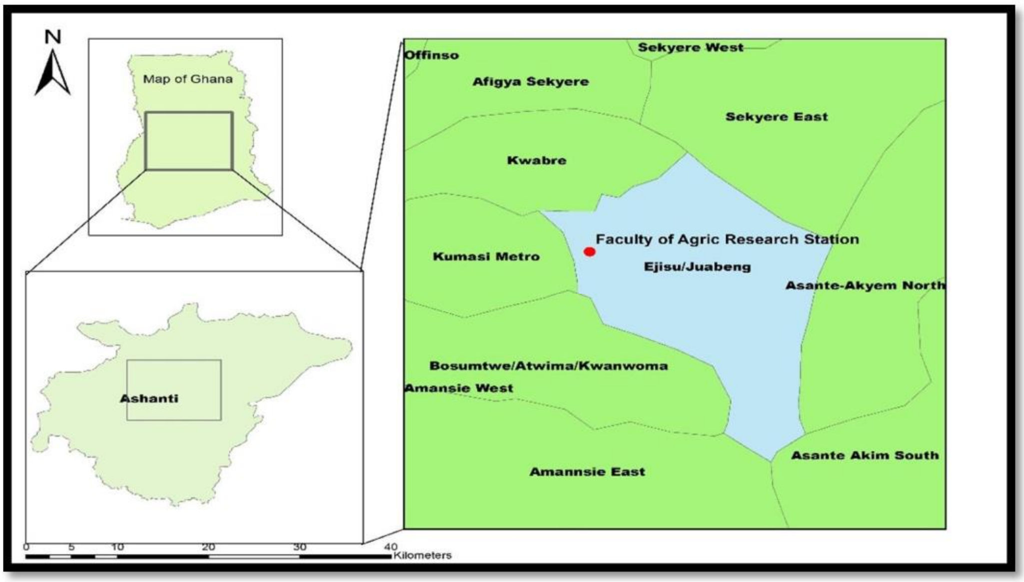


Figure 3.1: Map of study area

3.1.2 Land use history and agricultural practices of the study area

The portion of land used for the study had previously been cultivated with maize and cassava. Major crops cultivated in the area include maize, cowpea, cassava and yam.

Cropping pattern is either intercropping, rotation and/or monoculture. Land preparation is mostly by hoeing but where there is much grass, slash and burn followed by herbicide application on regenerating weed is used. Hoeing and hand pulling are the main weed controlling methods. Cropping is mainly rainfed.

3.1.3 Climate

Rainfall distribution in the semi-deciduous forest zone is bimodal. Major rainy season starts from March to July followed by a short dry spell in August and the minor rainy season commences from September to November. Mean annual rainfall is between 1300 and 1400 mm and mean monthly temperature is between 24 – 28 ^{o}C. However, the mean annual rainfall at the experimental site (< 200 mm) was far less than that of the entire agroecological zone.

3.2 Field experiment

The study was conducted for two years (four cropping seasons). The first and second field experiments were undertaken during the major and minor rainy seasons respectively in 2013. The third and fourth experiments were undertaken during the major and minor rainy seasons respectively in 2014.

3.2.1 Soil sampling and sample preparation

Samples for soil characterization were collected from two depths (0 – 15 cm and 15 – 30 cm) with an auger in each sub-sub plot. At each depth, composites were formed and subsamples were taken. The subsamples were air dried in the laboratory and further mixed during sieving with 2 mm mesh sieve and used for selected physical and chemical analyses. For soil bulk density, undisturbed soil samples were collected.

After crop harvest, disturbed and undisturbed soil samples were collected close to the base of plants in each sub-sub plot and at two depths (0 – 15 cm and 15 – 30 cm). Disturbed samples were air dried and sieved for analysis in the laboratory. Two sieving stages were used. Firstly, samples were passed through 4 mm mesh sieve after which 100 g each of the sieved sample was taken for wet and dry aggregates stability analyses. The remaining sample was further sieved through a 2 mm mesh sieve and the < 2 mm fraction was bagged for chemical analysis. Undisturbed soil samples were collected with a core sampler for bulk density measurement.

3.2.2 Experimental design and field layout

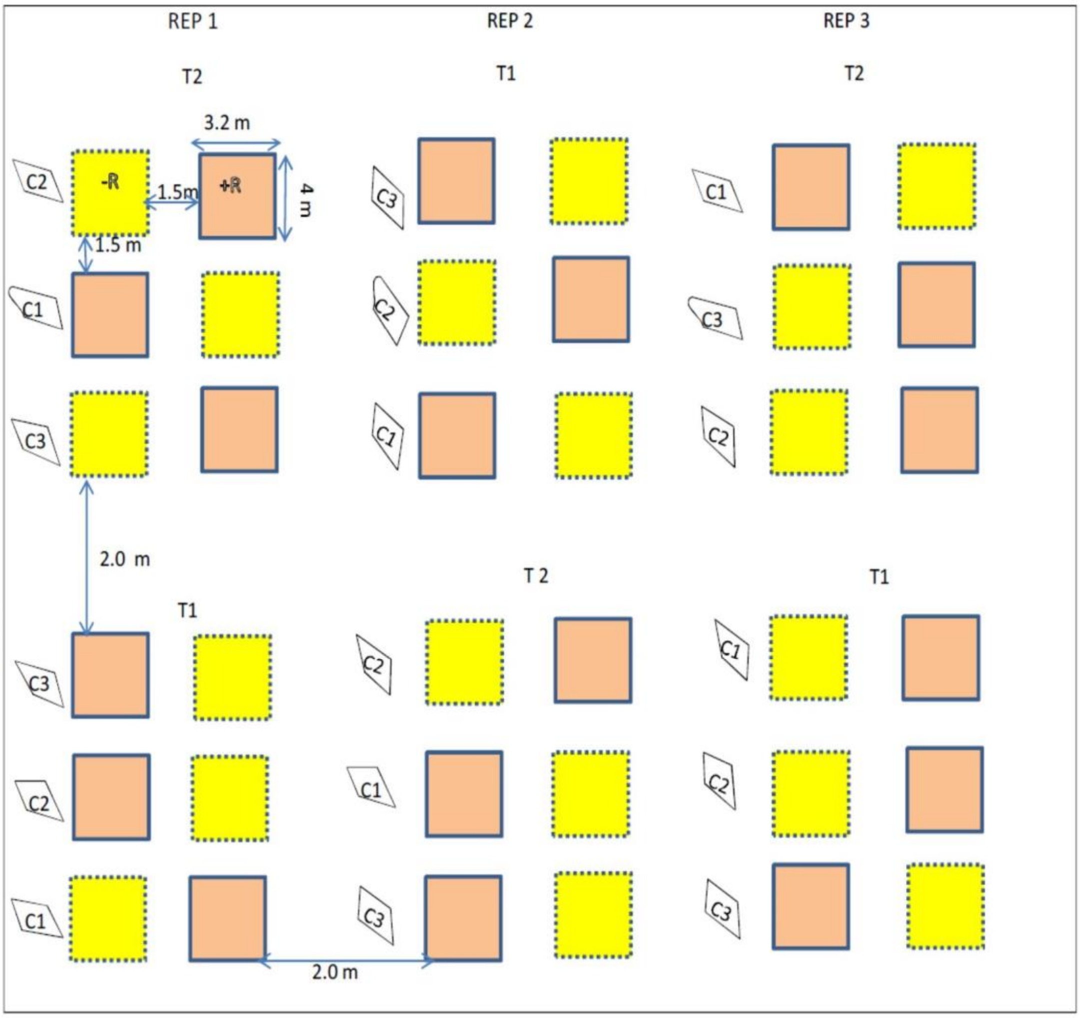
The experiment was a split-split plot arranged in randomized complete block design with three replications. The treatments were two levels each of tillage and crop residue mulch and three levels of crop rotation. Tillage was assigned to main plot, crop rotation to sub plot and crop residue mulch to sub-sub plot. The total land area used for the study measured 36 x 27.7 m (997.2 m^2). There were 12 sub-sub plots measuring 4.0 x 3.2 m in each replication. Main plots were 2.0 m apart while sub plots and sub-sub plots were 1.5 m apart (Figure 3.2).

3.2.3 Tillage methods

At the start of the experiment, only conventional tillage involving one pass disc ploughing and one pass disc harrowing was used. In the second and succeeding seasons, two tillage methods were used. Conventional tillage continued on randomly selected sections of the experimental area while on other sections, no-tillage was used for subsequent seasons. The study therefore compared continuous conventional tillage (CT - CT) and tillage rotation (CT - NT).

3.2.4 Tillage activity

Entry of plots by the tillage implement was done in reverse manner with tillage operation starting from one end of the plot and exiting upon completion of tillage at



TILLAGE (Main plot)	CROP ROTATION (Sub plot)	MULCHING (Sub-sub plot)
T1 = Conventional-no-tillage rotation	C1 = Cowpea-maize rotation	+R = Mulch
T2 = Continuous conventional tillage	C2 = Maize monoculture	-R = No-mulch
	C3 = Cowpea monoculture	

Figure 3.2: Layout of experimental field another end. Ploughing depth (20 – 30 cm) was estimated with the aid of a wooden rod inserted randomly at selected portions of the field cut by the disc plough.

3.2.5 Cropping system

Monoculture and cowpea-maize rotation (C-M-C-M) were the two main cropping systems used in this study (Table 3.1). Monoculture constituted maize (M-M-M-M) and cowpea (C-C-C-C) monoculture. Therefore, three levels of cropping systems were studied during the period.

3.2.6 Crop cultivars used

Early maturing varieties of maize (var. Omankwa) and cowpea (var. Asontem) obtained from the Crops Research Institute at Fumesua were used as test crops in this study. Omankwa has germination percentage ranging between 80 – 95 and emerged within 4 - 6 days after sowing (DAS). It reached physiological maturity within 75 – 90 DAS and is reported to yield about 3 – 4.7 Mg ha^{-1}. Asontem is also an early maturing, pest resistant and high yielding (3 Mg ha^{-1}) variety of cowpea with germination percentage in the range of 95 – 100 and emergence and physiological maturity periods of 3 – 4 DAS and 65 DAS, respectively.

3.2.7 Crop residue mulch

3.2.7.1 Type and characterization of mulch

Maize residue including stover and husk obtained *in situ* after crop harvest were used as mulch materials. Cowpea residue also obtained *in situ* included dried haulms. At the end of each cropping season, dried crop residues were cut, weighed, bagged and kept in store screened from direct sunlight, rainfall and termites, and used in succeeding season as mulch material.

Sub samples of crop residues were oven dried at 70 ^{o}C, milled and the fraction that passed through 1 mm sieve was assessed for total nitrogen, organic carbon, total phosphorus, calcium, magnesium and potassium.

Table 3.1 Description of tillage, crop rotation and residue mulch treatments

Year	Season	Tillage	Crop rotation	Residue mulch	
2013	Major	CT	Maize (M-M-M-M)	+R	-R
			Cowpea (C-C-C-C)	+R	-R
			Cowpea (C-M-C-M)	+R	-R
2013	Minor	CT-CT	Maize (M-M-M-M)	+R	-R
			Cowpea (C-C-C-C)	+R	-R
			Maize (C-M-C-M)	+R	-R
		CT-NT	Maize (M-M-M-M)	+R	-R
			Cowpea (C-C-C-C)	+R	-R
			Maize (C-M-C-M)	+R	-R
2014	Major	CT-CT-CT	Maize (M-M-M-M)	+R	-R
			Cowpea (C-C-C-C)	+R	-R
			Cowpea (C-M-C-M)	+R	-R
		CT-NT-NT	Maize (M-M-M-M)	+R	-R
			Cowpea (C-C-C-C)	+R	-R
			Cowpea (C-M-C-M)	+R	-R
2014	Minor	CT-CT-CT-CT	Maize (M-M-M-M)	--R	-R
			Maize (C-M-C-M)	+R	-R
			Cowpea (C-C-C-C)	+R	-R
			Maize (C-M-C-M)	+R	-R
		CT-NT-NT-NT	Maize (M-M-M-M)	+R	-R
			Cowpea (C-C-C-C)	+R	-R

CT is conventional tillage, NT is no tillage, M-M-M-M is maize monocropping, C-C-C-C is cowpea monocropping and C-M-C-M is cowpea-maize rotation. +R mulch, -R no mulch.

3.2.7.2 Amount and application of mulch

Mulch (+R) and No mulch (-R) were the two crop residues levels investigated in the experiment. For maize residues, 3.0 kg $plot^{-1}$, 7.2 kg $plot^{-1}$ and 6.3 kg $plot^{-1}$ equivalent to 2.34 Mg ha^{-1}, 5.63 Mg ha^{-1} and 4.92 Mg ha^{-1} respectively were applied consecutively in the second, third and fourth seasons. For cowpea, 6.5 kg $plot^{-1}$, 1.56 kg $plot^{-1}$ and 6.08 kg $plot^{-1}$ equivalent to 5.07 Mg ha^{-1}, 1.22 Mg ha^{-1} and 4.75 Mg ha^{-1} respectively were used.

Maize residue was applied only to plots cultivated with maize and cowpea residue applied to plots cultivated with cowpea. For plots cultivated with maize and cowpea in rotation, the residues of both crops were applied in rotation. Crop residues were applied to plots at the beginning of the cropping season after disc ploughing and harrowing.

3.3 Land preparation and plot demarcation

The study area was under natural fallow of grasses and tree stumps as at the commencement of the experiment. Therefore, for the first cropping season, native grass was cleared by weeding and tree stumps uprooted and moved out of the field together with grass biomass to a nearby plot. Initial grass biomass was 1.38 Mg ha^{-1}. For the subsequent cropping seasons, weeds were eliminated by chemical control. A non-selective herbicide (480 g glyphosate) was sprayed (60 ml in 30 *l* water equivalent to 300 ml a.i. ha^{-1}) two weeks ahead of conventional tillage. Boundaries of plots, paths between replications and within plots were demarcated using ranging poles, spirit level, tape measure, lines and pegs. Plots were subsequently identified with plot labels.

3.4 Sowing

Maize and cowpea seeds were sown on 19.06.2013, 24.06.2013, 02.05.2014 and 11.09.2014 for the four cropping seasons. Both seeds were sown manually to a depth of 2.5 cm aided by planting lines and pegs. Maize and cowpea were sown at a rate of three seeds per hill apiece. Plant spacing (inter and intra row spacing) was 80 x 40 cm for maize and 60 x 20 cm for cowpea. This therefore resulted in a plant population of 62500 ha^{-1} and 166 667 ha^{-1} for the former and the latter crops respectively.

3.5 Cultural practices

3.5.1 Thinning and refilling

Thinning was carried out to maintain the required plant population. Maize hills were thinned to two if more than two seedlings emerged. At the same time, plant stands where seedling emergence failed, replacements were done. Replacements for both maize and cowpea were done within seven days after sowing.

3.5.2 Fertilizer application

Fertilizer application rate of 0.115 kg N, 0.077 kg P_2O_5, and 0.077 kg K_2O per plot equivalent to per hectare rate of 90 kg N, 60 kg P_2O_5 and 60 kg K_2O was used in the study. The plant nutrient was supplied by compound and single mineral fertilizers applied by side placement 2 and 8 weeks after sowing (WAS) respectively. The fertilizers used were N.P.K 15-15-15 and urea (46 %). No mineral fertilizer was applied to cowpea.

3.5.3 Pest control

Two chemical formulations were used in insects and pests control fortnightly until physiological maturity of cowpea. Lambda Masta 2.5 EC (25 g lambda cyhalothrin) and Cymethoate Super EC (36 g cypermethrin and 400 g dimethoate) were sprayed at the rate of 80 ml in 30 *l* water equivalent to 800 ml a.i. ha^{-1} and 100 ml in 30 *l* water equivalent to 1000 – 1500 ml a.i ha^{-1}, respectively. Targeted insects were leaf worms, aphids, beetles, pod borers and thrips in cowpea and stalk borers in maize. Maize was sprayed with Lambda Masta 2.5 EC at 4 and 8 WAS.

Pests including rodents, birds and cattle were encountered. Birds and cattle were controlled by guarding and rodents by clearing bush close to the experimental area.

3.5.4 Weed control

Weeding was done manually by hand pulling as and when necessary but usually before the closure of plant canopy. Hand pulling involved pulling with the hand aided by cutlass. On tillage rotation plots, it was ensured that soil surface disturbance was minimized especially in no-till during weeding.

3.6. Harvesting and plant sample preparation

3.6.1 Maize grain and stover yield

Matured dried ears were handpicked from plants within an area of 6 m^2 marked in the middle crop row per plot. Grains were removed from ears, weighed and subsample taken for moisture content determination. Grain yield was corrected for moisture content at 15 % (Aflakpui *et al*., 2007). Stover from which ears were handpicked were clipped from the base close to the soil surface and weighed. A subsample was collected, bagged and oven dried at 70 ^{o}C for 48 h and used for moisture content determination and adjustment. Grain and stover yield were calculated as:

$$\text{Grain or stover yield (Mg ha }\quad) = \frac{\text{Yield /net plot (kg) x 10000 m}}{\text{Net plot area}}$$

3.6.2 Cowpea grain and haulm yield

Matured and dried pods were handpicked from plants within 6 m^2 marked area in the middle crop row. A subsample was taken from total pod per plot, weighed, oven dried at 70 ^oC for 48 h and reweighed for moisture content determination and adjustment at 13 % (Reddy, 2001). Plants from which pods were handpicked were cut at the soil surface, weighed immediately on the field and a subsample transported to the laboratory in sealed paper bags. The subsample was weighed, oven dried at 70 ^oC for 48 h and reweighed for moisture content determination and adjustment.

3.7. Sampling and preparation of plant residues for chemical analysis

Plant subsamples collected per plot for moisture content analysis were retained for chemical analysis. All subsamples per plot were cut and mixed in a basin forming a bulk sample. Three subsamples were randomly drawn from the bulk sample and used for chemical analysis.

The randomly drawn samples were further cut into pieces and dried for milling. Milling was done using an electronic miller. Milled plant materials were subsequently screened through 0.5 mm sieve and the sieved collected for total carbon, total nitrogen, total phosphorus and total potassium content.

3.8 Chemical analysis of plant residues

3.8.1 Determination of organic carbon

Organic carbon content of plant samples was determined using the wet oxidation method (Nelson and Sommers, 1982). In brief, 0.1 g of plant sample was weighed into 500 Erlenmeyer flask to which 10 ml 1.0 *N* $K_2Cr_2O_7$ solution and 20 ml of conc. H_2SO_4 were added and swirled. The mixture was left to cool on asbestos sheet. After 30 min, 200 ml distilled water and 10 ml orthophosphoric acid were added and titrated against

0.5 *N* Ferrous sulphate to a green end point in the presence of 2 ml diphenylamine indicator. Plant organic carbon was therefore calculated as:

$$\% \mathrm{C} = \frac{0.5 \times 1 \; (\mathrm{V} \quad - \mathrm{V}\;) \times 0.003 \times 1.33 \times 100}{0.1 \mathrm{~g}}$$

where: 0.5 = molarity of ferrous sulphate

V = volume of titrant used on blank

V = volume of titrant used on sample

0.003 = milli-equivalent weight of carbon in grams

1.33 = correction factor.

3.8.2 Determination of total nitrogen

The Kjeldahl digestion and titration method was used for total nitrogen analysis of plant materials (Okalebo *et al*., 1993). Two grams of plant material oven dried and milled to pass through a 0.5 mm sieve was weighed into a 500 ml Kjeldahl digestion flask. One spatula of catalyst (copper sulphate + sodium sulphate + selenium powder mixture) and 20 ml of concentrated H_2SO_4 were added. The mixture was heated to digest the plant material to a permanent clear green colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled water.

A 10 ml aliquot of the digest was transferred into a distillation flask and 20 ml of 40 % NaOH solution was added. Steam was allowed to flow into the flask. The ammonium distilled was collected into a 250 ml flask containing 15 ml of 4 % boric acid with mixed indicator of bromocresol green and methyl red. The distillate was titrated with 0.1 *N* HCl solution. A blank digestion, distillation and titration were also carried.

$$\% \text{ N} = \frac{14 \text{ x } (\text{a} - \text{b}) \text{ x } \quad \text{x } 100}{1000 \text{ x } 1}$$

where: 14 = atomic mass of nitrogen

a = volume of HCl used in sample titration

b = volume of HCl used in blank titration

= normality of standard HCl

100 = volume of digest

3.8.3 Determination of total phosphorus and total potassium

In determining total phosphorus and potassium, 0.5 g of plant material was weighed into clean ceramic crucible and ashed in a muffle furnace at a temperature of 500 ^{o}C for 4 h. The ash was poured into 50 ml centrifuge tube after cooling. Ten (10) ml distilled water and 10 ml acqua regia were added and the mixture shaken and centrifuged for 10 min at 3000 rpm (Jones and Case, 1990). The supernatant was decanted into clean vials for analysis.

3.8.3.1 Total phosphorus

A 5 ml aliquot of the digested sample was pipetted into a 50 ml volumetric flask. Five (5.0) millilitres of ammonium molybdate – ammonium vanadate solution was added and the volume of mixture was made up with distilled water (Bray and Kurtz, 1945).

The mixture was allowed to stand undisturbed for 30 minutes for colour development.

Standard curve was developed concurrently with P concentrations ranging from 0.0, 5.0, 10.0, 15.0, 20.0 mg P kg^{-1}. The absorbance of blank and the samples were read on the Jenway Colorimeter at a wavelength of 430 nm. A graph of absorbance against P concentration (ppm) was plotted. The blank and unknown standards were read and used for P calculation as follows:

$$\% \text{ P} = \frac{\text{Graph reading x absorbance}}{10}$$

where: 10 is the dilution factor

3.8.3.2 Total potassium

Total potassium was measured by the aspiration of the supernatant solution using a flame photometer and the emitted values read digitally. Flame photometer readings were calibrated with standard solutions prepared in concentrations of 0, 2, 4, 6, 8 and 10 µg ml^{-1}. A standard curve showing emitted values against concentration of solution was plotted. The standard curve was used in estimating total potassium in samples as follows:

$$\% \text{ K} = \frac{\text{Graph reading x \% Emission}}{100}$$

where: 100 is the conversion of µg to g.

3.9 Soil physical and chemical analysis

3.9.1 Particle size analysis

Fifty-one grams of air dried soil (< 2 mm) was weighed into 250 ml beaker. Fifty (50) ml calgon solution and 100 ml deionized water were dispensed unto the soil in the beaker. The suspension was shaken end to end and placed on a mechanical shaker where shaking continued for 30 min at 250 rpm. The mixture was subsequently transferred into 1 *l* sedimentation cylinder and made up to the mark with deionized water. Two readings with duplicates were taken using a hydrometer and a thermometer. The initial hydrometer (H_1) and thermometer (T_1 in ^oF) were taken after agitating the mixture with a plunger. Subsequently, the mixture was left undisturbed on a bench for 3 h after which the second hydrometer (H_2) and thermometer (T_2 in ^oF) readings were recorded. These readings were used in the calculation of % sand, % silt and % clay as follows:

$$\% \text{ Sand} = 100 - \ 2\,[\text{H} \ + \ \text{T} \ - (68 \text{ x } 0.2) - 2]$$

$$\% \text{ Clay} = 2[(\text{ H} \ - 2) + (\text{T} \ - 68)]$$

$$\% \text{ Silt} = 100 - \ [\% \text{ Sand} + \% \text{ Clay}]$$

Textural class was determined with the textural triangle.

3.9.2 Gravimetric soil moisture content

A 10 g of fresh soil was placed in a preweighed container (W_1) and the joint weight of the soil and container (W_2) recorded. The soil together with the container was oven dried at 105^{o}C for 24 h. The oven dried weight was recorded (W_3) and the difference in oven dried and fresh soil was calculated as follows:

$$\theta\text{m } (\text{g g} \quad) = \frac{\text{W} \ - \ \text{W}}{\text{W} \ - \ \text{W}}$$

3.9.3 Bulk density

Bulk density (ρ_b) was measured using the core sampler method. Samples used were collected the start of the experiment and after each crop harvest. A core sampler of 5.7

cm inner diameter was used to obtained undisturbed soil samples from two soil depths 0 – 15 cm and 15 – 30 cm with the aid of a mallet. Soil attached to the outer of the sampler was wiped clean and soil protruding beyond the edges of the sampler was cut with a knife. The fresh weight (W_1) of undisturbed soil was recorded and also the dry weight (W_2) upon cooling after oven drying at 105 ^oC for 48 h. Dry soil bulk density was therefore calculated as:

$$\rho\ (\mathrm{Mg\ m}\quad) = \frac{W\ -\ W}{V}$$

where: W = fresh soil weight,

W = dry soil weight, and

V = volume of the sampler (382.81 cm^3)

3.9.4 Volumetric moisture content

Volumetric moisture content (θv) was estimated from dry soil bulk density and gravimetric moisture content as follows:

$$\theta v\ (\mathrm{cm\quad cm}\quad) = \theta m \times \frac{\rho}{\rho}$$

where: θm = gravimetric moisture content

ρ = soil bulk density

ρ = density of water given as (1.0 Mg m^{-3})

3.9.5 Depth of water

Depth of water (θz) was calculated from volumetric moisture content and depth of soil as follows:

$$\theta z\ (\mathrm{mm}) = \theta v \times \text{depth of soil}$$

3.9.6 Total porosity

Total porosity ( ) was calculated as follows:

$$= 1 - \frac{\rho}{\rho}$$

where = soil bulk density

= particle density given as (2.65 Mg m^{-3})

3.9.7 Penetration resistance

Soil strength (resistance to penetration) was measured using a handheld protoc springtype penetrometer (product of Wagtech International). This type of penetrometer measured soil resistance to a maximum soil depth of 10 cm. The penetrometer measured soil resistance as force (kg) exerted by a cone (area) to penetrate soil. Measurement was done after each crop harvest. Penetration resistance (PR) was conducted at an initial soil moisture content of 0.10 - 0.13 cm^3 cm^3 in 2013 and 0.05 – 0.11 cm^3 cm^3 in 2014. A cone diameter of 16.54 mm was used, and inserted at an angel of 60^o. Three insertions and five (5) depth measurements per insertion were made after crop harvest in each sub-sub plot. Readings were made after seasonal rains to avoid differences in soil moisture content among treatments. Penetration resistance was therefore calculated as:

$$\text{PR (kPa)} = \frac{\text{Load (kg)}}{\text{Cone area (cm }\ \text{)}}$$

3.9.8 Saturated hydraulic conductivity

Saturated hydraulic conductivity (Ks) measurement was conducted on duplicate soil core samples taken from 0 – 15 cm depth in each sub-sub plot. Measurement was done on the field using the falling head permeameter method at an initial moisture content of 0.09 – 0.10 cm^3 cm^{-3}. Saturated hycraulic conductivity was measured in at the end of the fourth cropping season. The fall of the hydraulic head (H_t) from the initial (H_o) at the soil surface was measured as a function of time (t) using a stopwatch and a water manometer attached to a meter scale. Readings were taken until fall in hydraulic head reached 12 cm. Saturated hydraulic conductivity was therefore calculated as:

$$= \frac{}{1} \quad \frac{}{}$$

where: = surface area of the cylinder

= surface area of the soil

= initial hydraulic head

= time in seconds

= length of the soil sample (mm)

A graph of — against gives a slope of where: $= \frac{1}{}$

Since $=$ 1 in this case, was thus the product of the slope of the graph and the length of the soil sample. Thus, $=$

3.9.9 Infiltration

Infiltration study was conducted on the field after the fourth planting using the constant head method in a single ring infiltrometer (Klute and Dirksen, 1986). The initial soil moisture content (0.09 – 0.10 cm^3 cm^3) was noted prior to infiltration measurement. The infiltrometer was driven into the soil to a depth of 15 cm with the aid of a wooden plank and a mallet. A constant head of water, 5 cm was maintained from 1 *l* measuring cylinder after an initial instantaneous ponding. The volume of water used in maintaining the constant head was recorded at the 30 sec interval for the first 5 min, 60 sec interval for the next 5 min, 120 sec interval for 5 min, 180 sec interval for 15 min and 300 sec interval for 30 min.

The cumulative infiltration amount was plotted as a function of time . The slope of the cumulative infiltration amount taken at different time scales represented the infiltration rate . Infiltration rates were plotted against time and the steady state infiltrability was obtained at the point where the infiltration rate curve became almost parallel to the time axis. Plots of cumulative infiltration amount as function of the square root of time / for the first 5 min were performed and sorptivity was obtained from the slope of each plot.

3.9.10 Dry stable aggregates

Three set of sieves were arranged vertically in the order of 4 - 2 mm, 2 - 1 mm, and 1 - 0.25 mm on a mechanical shaker. Hundred grams of < 4 mm air dried soil was sieved through the sieves. Shaking continued for 10 min at 30 rpm. Therefore, the following soil aggregates were collected: 4 - 2 mm, 2 - 1 mm, 1 - 0.25 mm and < 0.25 mm. The weight of soil retained on each sieve was recorded. The < 0.25 mm was calculated as the difference between the initial soil weight and the sum of soil fractions retained on the three sieves. Subsequently, the stability of aggregates was measured using the mean weight diameter (Kemper and Rosenau, 1986) as expressed below:

$$(\quad) =$$

where: = mean diameter of each size fraction

= proportion of the total sample weight occurring in the corresponding fraction

3.9.11 Water stable aggregates

Three set of sieves 2 mm, 1 mm and 0.25 mm were used in assessing water stable aggregates (Kemper and Rosenau, 1986). A 100 g of air dried soil was gradually moistened to avoid spontaneous rupture of aggregates. The moistened soil was transferred onto the first sieve and sieving was done sequentially. Wet sieving of soil was done in a 2 *l* basin for 10 min at 30 rpm. Soil remaining on each sieve was quantitatively transferred into pre-weighed containers and oven dried at 105 ^{o}C. The stability of aggregates was assessed as:

$$(\quad) =$$

3.9.12 pH

Soil pH was determined in soil to water ratio of 1:2.5 with Suntex pH meter. A 10 g of soil was weighed into 50 ml glass beaker and 25 ml distilled water was added. The mixture was stirred continuously for 20 min and allowed to stand for 30 min. The pH meter was calibrated with buffer solutions of pH 4.0 and 7.0 and subsequently used to measured pH of soil samples.

3.9.13 Organic carbon

The wet oxidation method of Walkley and Black (Nelson and Sommers, 1982) was used in assessing soil organic carbon. Two grams of < 2.0 mm air dried soil was weighed into 500 ml Erlenmeyer flask. 10 ml 1.0 *N* potassium dichromate was added and also 20 ml concentrated sulphuric acid. A blank was included. The mixture was swirled to enhance soil-solution contact and was left to cool for half an hour. Thereafter, 200 ml distilled water, 10 ml orthophosphoric acid and 2.0 ml of diphenylamine indicator were added. The mixture was titrated against 0.5 *N* ferrous sulphate to a green end point. Soil organic carbon was calculated as follows:

$$\% \quad = \frac{(\quad - \quad) \text{ x } 0.003 \text{ x } 1.33 \text{ x } 100}{}$$

where: = molarity of the ferrous sulphate used in titration.

= blank titrated with0.5 *N* ferrous sulphate

= sampled titrated with 0.5 *N* ferrous sulphate

0.003 = milliequivalent weight of carbon expressed in grams (12/4000)

1.33 = conversion factor used for translating wet combustion C to the true C value. The wet combustion method is about 75 % efficient in estimating carbon value (i.e. 100/75 = 1.33).

3.9.14 Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation method. Ten grams of air dried soil (< 2 mm) was weighed into 500 ml Kjeldahl distillation flask. Ten millilitres of distilled water, 30 ml conc. H_2SO_4 and one spatula full of Kjeldahl mixture were added to the soil and mixed thoroughly. A blank was also prepared. The mixture was digested until clear (1 - 1 – h). The clear digest was decanted into 100 ml volumetric flask and made to the mark with distilled water. Ten millilitres of the aliquot solution and 20 ml 40 % NaOH was transferred into the reaction chamber of the Kjeldahl distillation apparatus for distillation. Distillate was collected over 10 ml

4 % boric acid and titrated against 0.1 *N* HCl using bromocresol green as indicator. Total nitrogen was therefore calculated as:

$$\% \text{ N} = \frac{14 \text{ x } (\text{a} - \text{b}) \text{ x } \quad \text{ x } 100}{1000 \text{ x } 1}$$

where: 14 = atomic mass of nitrogen

a = volume of HCl used in sample titration

b = volume of HCl used in blank titration

N = normality of standard HCl

100 = volume of digest

3.9.15 Available phosphorus

Available phosphorus was determined by the Bray 1 method. Five grams of air dried soil (< 2 mm) was weighed into 50 ml centrifuge tube. Thirty millilitres Bray 1 solution was added and shaken on a mechanical shaker for 5 min at 300 rpm and centrifuged for 5 min at 3000 rpm to obtain a clear solution. A 1 ml pipette of the clear supernatant solution was transferred into a clean centrifuge tube. Six millilitres of distilled water, 2 ml colour reagent and 1 ml ascorbic acid solution were added and mixed thoroughly. After full colour development, percent transmittance was measured at 520 nm wavelength on a spectrophotometer. Working standards containing 0, 1, 2, 4, 6, 8 and 10 µg P ml^{-1} were prepared and used in plotting a standard curve of absorbance verse ppm P. The concentration of P is soil extract was therefore obtained as:

$$\mathrm{P\ (mg\ P\ kg\quad soil) = Graph\ reading\ x\ 6}$$

3.9.16 Extraction of exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) and exchangeable acidity (aluminium and hydrogen) were determined by extracting soil (< 2 mm) with 1.0 *N* NH_4OAc solution and 1.0 *N* KCl respectively (Jones and Case, 1990). Ten grams of soil (< 2 mm) was weighed into labelled 100 ml extraction bottles and 100 ml 1.0 *N* ammonium acetate was added. The contents were shaken for 1 h and the extract filtered through Whatman No. 42 filter paper and the clear aliquot was collected into reagent bottles.

3.9.16.1 Determination of exchangeable calcium

A 10 ml of the aliquot was transferred into 100 ml Erlenmeyer flask. A10 ml potassium hydroxide solution and 1 ml triethanolamine were added. Few drops of potassium cyanide solution and crystals of cal-red indicator were also added for the colour development. The mixture was titrated against 0.02 *N* EDTA (ethylene, diamine tetraacetic acid) solution to blue endpoint.

3.9.16.2 Determination of exchangeable calcium and magnesium

A 10 ml of the aliquot was transferred into 100 ml Erlenmeyer flasks and 5 ml of ammonium chloride-ammonium hydroxide buffer solution was added. Subsequently,

1 ml triethanolamine was added followed by few drops of potassium cyanide and Eriochrome Black T solutions. This solution was titrated against 0.02 *N* EDTA solution to a blue endpoint and titre values recorded. Calcium and magnesium in solution was calculated as

$$\mathrm{Ca} \quad + \mathrm{Mg} \quad \mathrm{cmol}_{(\ )}\,\mathrm{kg} \quad \mathrm{soil} = \frac{0.02 \times V \times 1000}{W}$$

where: V = titre value recorded for used 0.02 *N* EDTA

0.02 = concentration of EDTA used

W = grams of soil used in the extraction

3.9.16.3 Determination of exchangeable magnesium

Exchangeable magnesium was calculated as the difference between calcium and magnesium and calcium only.

3.9.16.4 Determination of exchangeable potassium and sodium

Potassium and sodium in aliquot were determined by flame photometer. A 10 ml aliquot was transferred into glass tubes for flame photometer readings. Standard solutions of concentrations 0, 2, 4, 6, 8 and 10 ppm K^+ and Na^+ were formulated by diluting a stock solution of 100 ppm K^+ and Na^+ in a 100 ml volumetric flasks. Flame photometer readings of standard concentrations were used to plot a standard concentration curve from which sample concentrations were determined.

$$\text{Exchangeable K} \ \ (\text{cmol}_{(\ )}\ \text{kg} \quad \text{soil}) = \frac{\text{Graph reading x 100}}{\text{39.1 x W x 10}}$$

$$\text{Exchangeable Na} \ \ (\text{cmol}_{(\ )}\ \text{kg} \quad \text{soil}) = \frac{\text{Graph reading x 100}}{\text{23 x W x 10}}$$

where: W = grams of air dried soil used
39.1 = atomic weight of potassium

23 = atomic weight of sodium

3.9.16.5 Exchangeable acidity

A 3 g of air dried soil was leached into 100 ml Erlenmeyer flask with 50 ml 1.0 *N* KCl through Whatman No. 42 filter paper in a funnel. Five drops of phenolphthalein indicator was added to the leachate and titrated against 0.05 *N* NaOH solution to a colourless endpoint (McLean, 1965). The amount of the base used was equivalent to total acidity (Al^{3+} and H^+). Four (4) ml NaF was added to the colourless solution and was back titrated against 0.05 *N* HCl to a pink endpoint. The amount of acid used was equivalent to the amount of exchangeable aluminium. Exchangeable acidity and exchangeable aluminium were therefore calculated as:

$$\text{Exchangeable Al} \quad + \text{H} \quad \text{or Al} \quad (\text{meg}/100\ \text{g}) = \frac{\text{V x 0.05 x 100}}{\text{W}} = \text{V x 1.67}$$

where: V = titre value of NaOH or HCl

0.05 = normality of NaOH or HCl

W = weight of soil sample

3.9.16.6 Total exchangeable bases

Total exchangeable bases was computed as the sum of exchangeable calcium, magnesium, sodium and potassium.

3.9.16.7 Effective cation exchange capacity

Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases (Ca, Mg, Na and K) and aluminium.

3.9.16.8 Base saturation

Base saturation was calculated by dividing total exchangeable bases by effective cation exchange capacity multiplied by 100.

3.9.16.9 Mineralized carbon

Basal respiration of carbon in the form of carbon dioxide from soil was used in monitoring soil carbon mineralization. Twenty grams of air dry soil (< 2 mm) was weighed into 250 ml beaker. The soil was moistened to field capacity with 2 ml distilled water. Five millilitres 0.5 *M* NaOH was dispensed into a vial and placed in the presence of the soil and was sealed airtight. A blank was also prepared. The samples and blank were incubated at 31°C for 10 days. The amount of CO_2 trapped was measured by titration of the excess alkali with 0.5 *M* HCl (Raiesi, 2006). The amount of CO_2 evolved (Altikat *et al.*, 2012) was calculated as:

$$\mathrm{mg\ CO\ \ g\quad soil} = \frac{[\mathrm{CO} \qquad - \ \mathrm{CO} \qquad]}{\text{days of incubation}}$$

where: = emission from soil

= emission from blank

3.9.16.10 Particulate organic carbon

Twenty-five grams of air dried soil (< 2 mm) was weighed into 100 ml extraction bottle and 100 ml sodium hexametaphoshate solution was added. The mixture was shaken on a mechanical shaker for 1 h at 250 rpm. The content of the bottle was quantitatively transferred onto 53 µm sieve and rinsed with distilled water to wash-off silt and clay leaving behind sand particles. Soil fraction retained on the 53 µm sieve was transferred into pre-weighed cans and oven dried at 60 ^{o}C for 24 h (Wright *et al.*, 2007). The dried soil was ground to pass through 250 µm sieve. Two grams of the < 250 µm fraction was weighed into 500 ml Erlenmeyer flask and the wet combustion procedure of Walkley and Black was followed in analysing particulate organic carbon (Nelson and Sommers, 1982).

3.9.16.11 Water extractable organic carbon

A 2 g air dried soil (< 2 mm) was extracted with 20 ml deionized water by shaking on a mechanical shaker at 250 rpm for 1 h (Dou *et al.*, 2008). The solution was centrifuged and decanted, and water extractable organic carbon was measured using a modified method of Anderson and Ingram (1998). A 1 ml 0.1667 *M* potassium dichromate and 5 ml concentrated sulphuric acid were added to 4 ml of the aliquot in an Erlenmeyer flask. A blank was also prepared. The excess dichromate was titrated against 0.33 *M* ferrous ammonium sulphate. The indicator solution was prepared from *o*phenantholine monohydrate and ferrous ammonium sulphate hexahydrate. Extractable organic carbon was calculated as:

$$\% \text{ OC} = \frac{(\text{V} - \text{V}) \text{ x } \quad \text{x } 0.003}{\text{g}} \text{ x } \frac{\text{E}}{\text{S}} \text{ x } 100$$

where: V = blank titre

V = sample titre

= molarity of ferrous ammonium sulphate

g = mass of soil

E = extraction volume

S = aliquot volume used

3.10 Value cost ratio assessment

Average prices of crops prevailing at farm gate and cost of inputs during the period of study were used in computing profitability of the agricultural practices evaluated. Inputs used in the study were, plough-harrow, labour (crop residues, seed, fertilizer, and pesticides). Ploughing and harrowing cost was 200 Ghana cedis per hectare and labour cost for crop residue mulch application was estimated to be 362.31 Ghana cedis. Output prices at the farm gate (Hana 2015) were used in calculating profitability for the respective cropping periods. The average price of 0.70 and 0.85 Ghana cedis per kg of maize was used in 2013 and 2014 respectively while in both years, 2.20 Ghana cedis per kg of cowpea was used. Thus, value:cost ratio was calculated (Bontkes and Wopereis, 2003) as follows:

$$\text{VCR} = \frac{\text{Price of produce x Yield increase}}{\text{Cost of input}}$$

3.11 Statistical analysis

Statistical analysis was conducted in GenStat 12.1 (2009), a product of VSN International Ltd, UK. Analysis of variance (ANOVA) in a split-split plot design was performed to compare the variability between and within tillage, cropping system and mulch. In each case, repeated measurement was used to analyze treatment effect over time. Second order treatment interactions were presented as most of these showed significant effect on measured parameters. Significance was declared at F. probability < 0.05 and means separation was done using LSD. Pearson's correlation and regression analyses were also performed in Minitab student version 14.11.1 (1975 – 2003) to compare the relations of measured variables. The correlation matrix in Principal component analysis was used to identify the most important soil variables that influenced maize and cowpea grain yield in this study. Principal components were identified as those variables with eigenvalue (latent root) greater than 1 and which explained 60 % or more of the variability (Mumford *et al*., 2007; Eni *et al*., 2012).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Rainfall amount and distribution at the study site

4.1.1 Results

Monthly, seasonal and total rainfall amounts in 2013 and 2014 are presented in Table 4.1. Total annual rainfall in 2013 and 2014 represented 9.86 – 10.62 % and 14.17 – 15.27 % respectively of the annual average in the semi-deciduous forest zone. On the other hand, seasonal rainfall represented 63 % and 45 % of the total amount of rainfall received in 2013 and 2014, respectively. Rainfall amount was higher in 2014 making it 1.90 % wetter than 2013. Major season rainfall peaked in June while peak rainfall was recorded between September and October during the minor season. Seasonal rainfall was generally low and frequently interspersed with dry periods.

Table 4.1 Monthly, seasonal and annual rainfall at the experimental site in 2013 and 2014 cropping seasons

	Precipitation (mm)	
Month	**2013**	**2014**
January	0.00	35.00
February	21.00	19.33
March	17.30	24.75
April	12.80	17.90

May	15.60	8.33
June	19.67	18.22
July	12.00	13.00
August	0.00	12.80
September	19.88	13.50
October	15.89	20.43
November	4.00	15.25
December	0.00	0.00
Total	138.14	198.51
Seasonal	87.04	88.73

4.1.2 Discussion

Water availability in rainfed agriculture remains the most important factor limiting crop production. Crops require different amounts of water for growth (Adu *et al*., 2014). Maize requires 500 – 800 mm of water throughout its growing period, and cowpea, 300 – 500 mm (FAO, 2015). Thus, higher crop yield would be expected in wetter seasons. The generally low rainfall in the experimental site interspersed with dry periods suggests the tendency for moisture stress on plants (Peprah, 2014). Hence, practices that improve soil water storage such as those in this study might increase water availability and subsequently promote crop growth and yield in the area.

4.2 Initial soil physicochemical properties

4.2.1 Results

The physical and chemical properties of the soil used for the study are given in Table 4.2a and 4.2b respectively. The soil was a Haplic Plinthosol with a sandy loam texture consisting of 78 – 80 % sand, 8 – 10 % silt and 9 – 13 % clay in the 0 – 15 and 15 - 30 cm depths. Soil bulk density increased with soil depth with values ranging between

1.36 and 1.49 Mg m^{-3} in the two depths.

Table 4.2a Initial soil physical properties at the study site (2013)

Physical properties	Soil depth (cm) 0 - 15	15 - 30	CV (%)
Sand (%)	80.17	78.48	1.20
Silt (%)	10.25	8.16	10.70
Clay (%)	9.58	13.36	7.90
Texture	Loamy sand	Sandy loam	
Bulk density (Mg m^{-3})	1.36	1.49	6.40

The soil was very strongly to strongly acidic, low in organic carbon, low to medium in total nitrogen, high in magnesium but deficient in available phosphorus. It was poor in cation retention and deficient in potassium. The rating of these soil properties was based on the guidelines provided by Landon (1991) (Appendix 27).

4.2.2 Discussion

The texture of the experimental soil is indicative of a well-drained soil, suitable for the growth and yield of crops. According to Hudson (1975), the available moisture holding capacity of loamy sand and sandy loam is about 90 – 130 mm m^{-1} depth. Sustaining crop growth and yield of such soils would require management practices such as mulching, that control unproductive evaporation for enhanced in-situ moisture storage.

Table 4.2b Initial soil chemical properties (2013)

Chemical properties	Soil depth (cm) 0 – 15	15 – 30	CV (%)
pH^v	4.62	5.26	9.50
Organic carbon (%)	1.39	1.12	1.80
Total nitrogen (%)	0.26	0.20	3.00
Av^w. phosphorus (mg kg^{-1})	8.92	3.57	11.95
Basic cations (cmol$_{(+)}$ kg^{-1} soil)			
Ex^x. Na^+	0.10	0.08	11.10
Ex. K^+	0.19	0.14	12.10
Ex. Ca^{2+}	2.03	3.18	7.00
Ex. Mg^{2+}	2.54	1.33	10.20
TEB^y	4.85	4.75	7.40
Ex. Acidity	0.53	0.84	8.22

ECEC[z]	5.40	5.58	7.60
Base saturation (%)	90.11	84.77	0.80

[v] 1:2.5 soil:water slurry; [w] Available phosphorus; [x] Exchangeable; [y] Total Exchangeable Bases; [z] Effective Cation Exchange Capacity.

The bulk density was typical of a sandy loam and favourable for the growth of most plants, including maize and cowpea. The increase in bulk density with depth is a general observation and may be alluded to compactive effect of cultivation, soil settling and drecrease in organic matter content as observed in this study. However, a bulk density beyond 1.6 Mg m^{-3} can restrict plant root growth as pointed out by Lampurlane´s and Cantero-Martı´nez (2003). Tillage practices that maintain bulk density < 1.6 Mg m^{-3} would therefore be preferable.

In order to sustain crop growth and yield, the low organic carbon and NPK in the soil would require replenishment strategies to enhance the soil nutrients and more so, organic matter. The latter is a major source of N and P as indicated by the regression equation relating organic carbon and NPK with R^2 values of 0.93, 0.99 and 0.66 respectively (Appendix 2). As predictive equations, a unit increase in organic carbon increases N, P and K by 0.22 %, 20 mg kg^{-1} and 0.17 $cmol_{(+)}$ kg^{-1} soil respectively. Organic matter further reduces the solubility of aluminium and iron through the formation of organic complexes (Hernández-Soriano, 2012). Thus as indicated by the Pearson’s correlation values (Appendix 1), organic carbon was negatively correlated with exchangeable acidity with an r = - 0.97. High solubility of aluminium tends to increase soil acidity and decreases phosphorus availability (Ogban *et al*., 2008).

Exchangeable acidity was therefore positively correlated with pH with r = 0.74 (Appendix 1).

4.3 Nutrient concentrations of maize and cowpea residues used as mulch

4.3.1 Results

The nutrient content of cowpea haulms and maize stover are presented in Tables 4.3a and 4.3b respectively. In Table 4.3c, a comparison of the two crop residues is presented. Organic carbon content, total phosphorus, total potassium and carbonnitrogen ratio of cowpea residues were higher in 2013 than in 2014. Total N content of cowpea haulm was however 9.73 % lower in 2013 than 2014. Maize stover also recorded 8.07 %, 13.41 % and 58.33 % higher organic carbon, total potassium and total P respectively in 2013 than 2014. On the whole, the nutrient content of cowpea haulm was superior to maize stover (Table 4.3c).

Table 4.3a Nutrient concentrations of cowpea haulms in 2013 and 2014 cropping seasons

	Year			
Nutrient component	**2013**	**2014**	**CV (%)**	**%difference**
Organic carbon (%)	31.32	28.93	0.9	7.63
Total nitrogen (%)	1.02	1.13	0.1	10.78
Total phosphorus (%)	0.24	0.18	11.0	25
Total potassium (%)	2.13	1.76	0.3	17.37
C:N ratio	30.62	25.49	1.0	16.75

Table 4.3b Nutrient concentrations of maize stover in 2013 and 2014 cropping seasons

	Year			
Nutrient component	**2013**	**2014**	**CV (%)**	**%difference**
Organic carbon (%)	27.13	24.94	7.2	8.07

Total nitrogen (%)	0.62	0.73	9.6	17.74
Total phosphorus (%)	0.12	0.05	80.0	58.33
Total potassium (%)	1.64	1.42	25.0	13.41
C:N ratio	43.48	34.21	2.7	21.32

Table 4.3c Comparison of nutrient concentrations in maize stover and cowpea haulm

	Residue type			
Nutrient component	**Cowpea**	**Maize**	**CV (%)**	**%difference**
Organic carbon (%)	30.12	26.03	6.1	13.57
Total nitrogen (%)	1.08	0.67	8.3	37.96
Total phosphorus (%)	0.21	0.09	39.5	57.14
Total potassium (%)	1.95	1.53	16.3	21.53
C:N ratio	28.05	38.84	13.1	27.78

4.3.2 Discussion

The nutrient content of maize and cowpea points to poor residue quality, suitable for mulching. Crop residues with < 2.5 % nitrogen, and < 0.25 phosphorus if incorporated could immobilize soil nitrogen and phosphorus respectively (Fening *et al*., 2009). Poor residue quality suggests reduced degradability and higher potential for water capture and reduced unproductive evaporation.

According to Choudhary *et al.* (2013), the quality of plant material corresponds positively with the amount of nutrients available for uptake. Thus the low crop residue quality recorded in this study accords with the low total nitrogen, available phosphorus and exchangeable potassium contents of the sandy loam. An analysis of relationships between soil and plant parameters showed that available phosphorus and exchangeable potassium accounted for 90.0 % and 74.4 % variation respectively in plant nutrient composition (Appendix 4).

4.4.0 The impact of tillage, crop rotation and mulching on soil bulk density

4.4.1 Results

The results of the impact of tillage, crop rotation, mulching and their interactions on bulk density, which was used as proxy for soil compaction are presented in Table 4.4a and 4.4b. Bulk density varied with depth under each tillage practice but their differences were not significant except in 2014 (Table 4.4b). The general trend of bulk density increasing with depth was observed. Among the tillage practices, the CT – NT consistently recorded lower bulk density than the CT – CT at all depths. The differences, however, were not significant except for the 0 – 15 cm depth in 2014.

The impact of crop rotation on bulk density differed significantly only at the 15 – 30 cm and 0 – 15 cm depths in 2013 (Table 4.4a) and 2014, respectively. In the former case, bulk density ranked as C – C > M – M > C – M with values ranging from 1.43 to 1.56 Mg m^{-3}. The significant difference was observed only in C – C and C – M. In 2014, bulk density at the 0 – 15 cm varied from 1.39 to 1.43 Mg m^{-3} with a decreasing trend of C – M > C – C > M – M. The difference in the bulk density of the former two

Table 4.4a Effect of tillage, crop rotation, mulching and their interactions on soil bulk density in 2013 cropping season

	2013 Soil bulk density (Mg m^{-3}) Soil depth (cm)			
Practice	0 – 15	15 – 30	CV (%)	$LSD_{0.05}$
CT – CT	1.52	1.53	8.8	ns
CT – NT	1.50	1.48	8.5	ns
CV (%)	11.3	7.6		
$LSD_{0.05}$	ns	ns		
Crop rotation				
C – C	1.51	1.56	7.3	ns
M – M	1.56	1.50	8.7	ns
C – M	1.44	1.43	11.5	ns
CV (%)	11.0	7.0		
$LSD_{0.05}$	ns	0.08		
Mulching				
-R	1.61	1.52	7.5	0.07
+R	1.40	1.48	9.2	ns
CV (%)	8.8	7.8		
$LSD_{0.05}$	0.09	ns		
Interactions				
CT – CT/C – C/-R	1.63	1.61	3.7	ns
CT– CT/ C-C/+R	1.48	1.55	6.9	ns
CT– CT/M–M/-R	1.70	1.60	5.2	ns
CT– CT/M–M/+R	1.41	1.48	4.3	ns
CT– CT/C–M/-R	1.58	1.49	2.7	ns
CT– CT/C–M/+R	1.31	1.45	2.9	ns
CT – NT/C – C/-R	1.58	1.55	4.1	ns
CT–NT/ C – C/+R	1.36	1.55	4.1	ns
CT–NT/M–M/-R	1.57	1.51	2.2	ns
CT–NT/M–M/+R	1.56	1.43	4.1	ns
CT–NT/C–M/-R	1.58	1.36	7.3	ns
CT–NT/C–M/+R	1.30	1.43	8.9	ns
Mean	1.51	1.50		
CV (%)	8.7	7.3		
$LSD_{0.05}$	0.22	0.18		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns:

not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Table 4.4b Effect of tillage, crop rotation, mulching and their interactions on soil bulk density in 2014 cropping season

	2014 Bulk density (Mg m^{-3})			
	Soil depth (cm)			
Practice	0 – 15	15 – 30	CV (%)	$LSD_{0.05}$
CT – CT	1.47	1.57	4.7	0.04
CT – NT	1.39	1.59	3.4	0.03
CV (%)	3.5	4.5		
$LSD_{0.05}$	0.034	ns		
Crop rotation				
C – C	1.44	1.59	2.8	0.03
M – M	1.39	1.55	3.7	0.04
C – M	1.45	1.58	6.1	0.07
CV (%)	4.1	4.5		
$LSD_{0.05}$	0.04	ns		
Mulching				
-R	1.43	1.61	4.2	0.04
+R	1.42	1.54	4.3	0.04
CV (%)	4.5	4.1		
$LSD_{0.05}$	ns	0.04		
Interactions				
CT – CT/C – C/-R	1.45	1.64	2.0	0.11
CT– CT/ C-C/+R	1.45	1.54	2.4	ns
CT– CT/M–M/-R	1.45	1.64	0.6	0.03
CT– CT/M–M/+R	1.42	1.52	1.0	0.05
CT– CT/C–M/-R	1.54	1.62	2.5	ns
CT– CT/C–M/+R	1.45	1.42	2.4	ns
CT – NT/C – C/-R	1.42	1.57	3.2	ns
CT–NT/ C – C/+R	1.43	1.62	0.7	0.03
CT–NT/M–M/-R	1.35	1.53	1.0	0.04
CT–NT/M–M/+R	1.33	1.53	1.43	0.07
CT–NT/C–M/-R	1.34	1.63	0.8	0.04
CT–NT/C–M/+R	1.44	1.63	0.5	0.02
Mean	1.42	1.57		
CV (%)	2.0	1.4		
$LSD_{0.05}$	0.04	0.03		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

rotations was not significant. Bulk density under each crop rotation did not differ significantly with depth in 2013 but was significantly ($P < 0.05$) higher at the 15 – 30 cm than the 0 – 15 cm depth in 2014.

Mulching generally recorded lower bulk density than no-mulch at both depths with the differences being significant at the 0 – 15 cm and 15 – 30 cm depths in 2013 and 2014 respectively. On the other hand, bulk density under no-mulch was significantly ($P < 0.05$) lower at the 0 – 15 cm depth than the 15 – 30 cm depth in 2013 and vice versa in 2014. However, under mulching, bulk density was lower in the 0 – 15 cm than the 15 – 30 cm with only the latter differences being significant ($P < 0.05$).

The tillage x crop rotation x mulching interaction significantly ($P < 0.05$) influenced bulk density at both depths with lower values often recorded under interactions which included mulching in both years.

4.4.2 Discussion

Conventional tillage has both short-term benefits and long-term consequences. Among the short-term benefits are the elimination of crusting and surface sealing, and reduction of soil compaction manifested in reduced bulk density. These improvements, however, are transient and are nullified later in the season with values of bulk density reverting to its initial or higher values. This is mainly due to the infilling of the macropores created during the ploughing by the soil particles produced through pulverization of soil aggregates resulting in re-compaction. In the long-term, the seasonal cycle of this process by repeated conventional tillage enhances compaction which is exacerbated by the compressive effect of increased wheel traffic, rainfall-induced consolidation and soil structure deterioration. The latter is through reduction in soil organic binding agents resulting from rapid decomposition of and reduction in soil organic matter. The long-term consequences include decreased soil macroporosity, biological activity, nutrient cycling, soil infiltrability, hydraulic conductivity, increased runoff, reduced water storage and crop productivity. These impacts may be manifested at both surface and subsoil.

In this study, the CT – CT and CT – NT of 2013 increased the initial bulk density of the experimental field at both 0 – 15 cm and 15 – 30 cm depths. However, the differences in bulk density under each tillage practice (intra – treatment) and between the tillage practices (inter – treatments) at the two depths were not significant.

In 2014, the intra-treatment differences in bulk density at the two depths were significant ($P < 0.05$) with the 0 – 15 cm recording lower values than the 15 – 30 cm depth. On the other hand, while CT – CT recorded significantly ($P < 0.05$) higher bulk density at the 0 – 15 cm than the CT – NT, the differences at the 15 – 30 cm depth was not significant. The impact of tillage was therefore felt more at the 0 – 15 cm than 15 – 30 cm depth. The cushioning effect of surface residue of the CT – NT rotation at the 0 – 15 cm depth against the impact forces of raindrops and the reduced wheel traffic may account for the observed lower bulk density. This is indicative of the advantage of a one-time conventional tillage (CT) followed in subsequent seasons by no-till (NT) over that of continuous conventional tillage (CT – CT) in reducing soil compaction. The implicit benefits include improved soil infiltrability, hydraulic conductivity, maintenance of larger aggregates sizes and stability and delayed onset of runoff generation as amply shown by the experimental results on the parameters.

Besides tillage, the bulk density of the soil was impacted upon by crop rotation. The cowpea-maize rotation (C – M) and continuous maize monoculture (M – M) tended to decrease bulk density more than continuous cowpea monoculture (C – C).

The differences in the rooting system of maize and cowpea appear to be implicated in this observation. As observed by Halabuk (2006), plant root weight explained 52 % variation in his measured bulk density. In this study, fibrous rooting system of maize which accumulate within the 0 – 60 cm depth, had an apparent greater potential to bind loose soil particles and enhance aggregates stability than the tap root system of cowpea which has an effective rooting depth of 120 cm (Hudson 1975). Thus, in 2013, maize following cowpea reduced the bulk density under the latter crop from 1.56 Mg m^{-3} to 1.43 Mg m^{-3} at the 15 – 30 cm depth. For the same underlying reason, the continuous maize significantly recorded lower bulk density at the 0 – 15 cm depth than either C – C or C – M rotation in 2014.

As a cover, crop residue mulch also reduced bulk density relative to no-mulch. The influence of mulching in reducing bulk density may be physical, chemical or biological. Physically, the mulch protects the soil against the compactive forces of wheel traffic and raindrop impact; reduced soil particles dispersion, surface sealing and crusting, direct insolation, evaporation and the cycle of wetting and drying process at the soil surface. These result in lower bulk density. Chemically, mulching increases organic matter, soil aggregation and stability, all of which reduce bulk density as reported by several researchers (Mulumba and Lal, 2008; Ghuman and Sur, 2001). Biologically, mulching increases soil microbial activity which contributes to stable aggregate formation and reduced compaction. It is therefore not surprising that mulching consistently reduced bulk density relative to no-mulch. This accords with the observation of Khan *et al*. (2014).

The results further showed that, the tillage x crop rotation and mulching interaction significantly influenced bulk density. The implication is that the magnitude of the impact of the factors on bulk density depends on the level of each other. The overall impact of the interactions showed a complementary effect under CT – CT/C – M/+R, CT – NT/C – M/+R, CT – CT/M – M/+R and CT – NT/M – M/+R in reducing bulk density. The

interactions thus recorded lower bulk densities than the main effect of each factor acting sole. In all cases, the importance of mulching in reducing bulk density was amply demonstrated.

4.5.0 The impact of tillage, crop rotation and mulching on penetration resistance

4.5.1 Results

The impact of tillage, crop rotation and mulching on penetration resistance is presented in Table 4.5

Continuous conventional tillage (CT – CT) recorded higher penetration resistance than

CT – NT in both years. However, the difference in the values recorded was significant ($P < 0.05$) only in 2013.

Crop rotation did not cause any significant differences in penetration resistance, showing similarity with the impact of mulching in 2013. However, in 2014 mulching impact on penetration resistance varied significantly with mulch recording lower values than nomulch. The tillage x crop rotation x mulching, on the other hand, significantly ($P < 0.05$) affected penetration resistance. The highest and lowest penetration resistance were **Table 4.5 Effect of tillage, crop rotation and mulching on penetration resistance**

Practice	Penetration resistance (kPa) 2013	2014	
	Soil depth (cm)		
Tillage	0 - 10	0 - 10	AVERAGE
CT – CT	726.0	888.0	807.0
CT - NT	539.0	814.0	676.5
CV (%)	26.8	21.9	23.8
$LSD_{0.05}$	111.5	ns	117.03
Crop rotation			
C – C	615.5	852.0	733.7
M – M	630.2	846.3	738.2
C – M	651.8	854.8	753.3
CV (%)	43.1	32.7	24.7
$LSD_{0.05}$	ns	ns	ns
Mulching			
-R	606.1	914.3	760.2
+R	658.9	787.7	723.3
CV (%)	31.3	21.3	22.8
$LSD_{0.05}$	ns	62.2	ns
Interactions			
CT– CT/C – C/-R	711.1	765.4	738.3
CT– CT/ C-C/+R	741.6	937.4	839.5
CT – CT/M–M/-R	642.2	1046.2	844.2
CT– CT/M–M/+R	807.5	914.5	861.0
CT– CT/C–M/-R	662.4	878.8	770.6
CT–CT/C–M/+R	791.3	786.0	788.6
CT–NT/C – C/-R	509.3	1036.3	772.8
CT– NT/ C – C/+R	500.1	668.8	584.5
CT–NT/M–M/-R	571.1	679.4	625.3

CT–NT/M–M/+R	500.1	744.9	622.5
CT–NT/C–M/-R	540.7	1079.6	810.2
CT–NT/C–M/+R	612.7	674.9	643.8
Mean	632.5	851.0	741.8
CV (%)	28.6	13.6	18.7
$LSD_{0.05}$	292.6	186.70	246.11

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

recorded under CT – CT/M – M/+R and CT – NT/C – C/+R respectively. In all cases, the 2013 resistance values were lower than those of 2014. The results further showed penetration resistance to be positively correlated with bulk density (Appendix 5).

However, the correlation with total porosity and saturated hydraulic conductivity was negative (Appendix 5).

4.5.2 Discussion

Increasing wheel traffic under continuous conventional tillage and the clogging of macropores by pulverized soil aggregates increase bulk density. In consonance, penetration resistance also increase due to the positive correlation between penetration resistance and bulk density as shown by the results of this study. The implication is that penetration resistance increases with increasing bulk density as similarly reported by other authors (Osunbitan *et al*., 2005; Khan *et al*., 2014). Increasing penetration resistance, in turn, adversely affect soil infiltrability, hydraulic conductivity, aeration, seedling emergence, plant root and shoot growth and crop yield. Any tillage practice that reverses these negative trends tends to create favourable soil conditions for crop growth. It is in this context that the CT – NT has an advantage over CT – CT. The lower penetration resistance of the former could be alluded to reduced wheel traffic, tillage intensity and the presence of vegetal material which minimize soil compaction, the impact forces of raindrops and surface sealing, an agent of high soil strength (Olaoye 2002; Shi *et al*., 2012).

Although crop rotation did not effect any significant differences in penetration resistance, it is worth noting that crops affect and are affected by penetration resistance. Plants influence soil strength through additions of organic matter, root exudates, soil aggregation and creation of macropores. The growth and development of plant roots and decomposition of crop residues increase soil macroporosity, reduce compaction and penetration resistance (Osunbitan *et al*., 2005). The significant benefit of mulching in reducing penetration resistance on the other hand became evident through its main effect and its interaction with tillage and crop rotation but more so with tillage rotation (CT – NT) and continuous cowpea (C – C). The significant interaction of the treatments on penetration resistance in both years of the study, however imply that the impact of the interacting factors depend on the level of each other.

4.6.0 The impact of tillage, crop rotation, mulching and their interactions on total porosity

4.6.1 Results

The results of total porosity as impacted upon by tillage, crop rotation, crop residue mulch and their interaction are presented in Table 4.6a and 4.6b.

Tillage significantly (P < 0.05) affected total porosity in 2013 (Table 4.6a) but not in 2014 (Table 4.6b). In both years CT – NT recorded higher porosity than CT – CT. Within tillage practices, similar total porosity was recorded at both 0 – 15 and 15 – 30 cm depths in 2013.

However, in 2014, significantly (P < 0.05) higher total porosity was recorded at the 0 – 15 cm than 15 – 30 cm depth.

Cropping system also influenced the magnitude of the total porosity with the differences being significant (P < 0.05) at the 15 – 30 cm depth and 0 – 15 cm depth in 2013 and 2014, respectively. In the former situation, the total porosity was in the order of C – M > M – M > C – C whilst the trend in the latter was M – M > C – M > C – C. As in the case of tillage, higher total porosity was recorded at the 0 – 15 cm than the 15 – 30 cm depth within each cropping system.

Table 4.6a Effect of tillage, crop rotation, mulching and their interactions on total porosity in 2013 and 2014

	2013 Total porosity			
Practice	**Soil depth (cm)**			
Tillage	0 – 15	15 – 30	CV (%)	$LSD_{0.05}$
CT – CT	0.40	0.40	11.3	ns
CT – NT	0.45	0.45	11.4	ns
CV (%)	13.8	8.3		
$LSD_{0.05}$	0.04	0.02		
Crop rotation				
C – C	0.42	0.40	10.3	ns
M – M	0.41	0.43	12.0	ns
C – M	0.45	0.45	13.8	ns
CV (%)	14.7	9.2		
$LSD_{0.05}$	ns	0.03		
Mulching				
-R	0.39	0.42	10.8	0.02

+R	0.46	0.43	11.0	ns
CV (%)	11.8	10.2		
$LSD_{0.05}$	0.03	ns		
Interactions				
CT – CT/C – C/-R	0.35	0.38	3.5	ns
CT– CT/ C – C/+R	0.47	0.41	7.5	ns
CT– CT/M–M/-R	0.34	0.39	2.5	0.03
CT– CT/M–M/+R	0.41	0.42	6.5	ns
CT– CT/C–M/-R	0.37	0.41	2.3	0.03
CT– CT/C–M/+R	0.47	0.41	0.3	0.004
CT – NT/C – C/-R	0.43	0.42	5.0	ns
CT–NT/ C – C/+R	0.45	0.41	8.3	ns
CT–NT/M–M/-R	0.42	0.43	3.9	ns
CT–NT/M–M/+R	0.46	0.47	10.1	ns
CT–NT/C–M/-R	0.42	0.50	9.9	ns
CT–NT/C–M/+R	0.53	0.49	8.8	ns
Mean	0.43	0.43		
CV (%)	9.1	5.8		
$LSD_{0.05}$	0.06	0.04		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns:

not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Table 4.6b Effect of tillage, crop rotation, mulching and their interactions on total porosity in 2014

Practice	2014 Total porosity Soil depth (cm)			
Tillage	0 – 15	15 – 30	CV (%)	$LSD_{0.05}$
CT – CT	0.45	0.40	6.0	0.01
CT – NT	0.46	0.40	5.2	0.01
CV (%)	4.5	6.7		
$LSD_{0.05}$	ns	ns		
Crop rotation				
C – C	0.45	0.39	3.6	0.01
M – M	0.47	0.41	3.9	0.01
C – M	0.45	0.40	8.1	0.02
CV (%)	4.2	6.6		
$LSD_{0.05}$	0.01	ns		
Mulching				

-R	0.46	0.39	4.9	0.01
+R	0.46	0.41	5.4	0.01
CV (%)	4.7	5.9		
$LSD_{0.05}$	ns	0.01		
Interactions				
CT – CT/C – C/-R	0.46	0.38	0.4	0.005
CT– CT/ C – C/+R	0.44	0.40	5.4	ns
CT– CT/M–M/-R	0.46	0.38	0.9	0.01
CT– CT/M–M/+R	0.47	0.42	5.0	ns
CT– CT/C–M/-R	0.43	0.38	9.1	ns
CT– CT/C–M/+R	0.45	0.43	7.6	ns
CT – NT/C – C/-R	0.45	0.40	2.3	0.03
CT–NT/ C – C/+R	0.46	0.39	1.7	0.02
CT–NT/M–M/-R	0.48	0.41	1.2	0.01
CT–NT/M–M/+R	0.48	0.42	2.6	0.04
CT–NT/C–M/-R	0.47	0.38	6.5	ns
CT–NT/C–M/+R	0.45	0.41	9.0	ns
Mean	0.46	0.40		
CV (%)	4.2	6.0		
$LSD_{0.05}$	ns	ns		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns:
not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Mulching on the other hand, produced significantly ($P < 0.05$) higher total porosity than no-mulch at the 0 – 15 cm and 15 – 30 cm depth in 2013 and 2014, respectively. Under no-mulch, significantly lower total porosity was recorded at the 0 – 15 cm depth than the 15 – 30 cm depth. The converse was true in 2014 and in the case of mulching.

The impact of the tillage x crop rotation x mulching interaction was significant at both depths only in 2013. Interactions involving mulching tended to record higher total porosity, especially, at the 0 – 15 cm depth. Total porosity was found to correlate positively and significantly with saturated hydraulic conductivity.

4.6.2 Discussion

Edaphic factors which affect the root atmosphere are of particular importance in influencing the growth and production of agricultural crops. Among the soil physical factors are bulk density, total porosity, infiltration, hydraulic conductivity, moisture content and availability. These factors are influenced by tillage, crop rotation, crop residue mulch and their interactions at variable spatial and temporal scales.

The quantity of pores and their size distribution in the soil are among the general indicators of the physical condition of soils for sustaining improved crop growth. As in the case of bulk density, pore characteristics undergo changes between and within seasons making it difficult to quantify their influence on crop productivity. Other important complicating features of pores influencing aeration, water movement and root penetration in soils that need to be considered in interpreting the impacts of porosity are tortuosity and continuity.

The results of the study showed tillage to significantly influence total porosity with the CT – NT recording higher values than CT – CT. A match of the values with bulk density under the tillage practices showed that as bulk density increased, total porosity correspondingly decreased (Appendix 5). Thus, the same factors such as the compactive effect of increased wheel traffic and raindrop impact ascribed to the observed increase in bulk density under continuous conventional tillage (CT – CT), reduced total porosity. On the other hand, the reduced wheel traffic and absorption of raindrop impact energy by crop residues of no-tillage, complemented by increased organic matter with its implicit enhancement of microbial activity, soil aggregate stability and macropore formation reduced soil compaction and increased total porosity.

Alongside these impacts, crop type and rotation significantly influenced total porosity.

The results showed M – M and C – M to record higher total porosity at the 0 – 15 cm and 15 – 30 cm depth respectively. The concentration of the greater fibrous root biomass of maize than cowpea at the 0 – 15 cm depth, similarly reported by Adiku *et al*. (2008), and its positive effect on soil aggregation may account for the higher total porosity. For the same reasons, M – M, was more effective in increasing total porosity than C – C. Dormaar and Carefoot (1996) indicated that greater root mass enhanced aggregation because of the higher polysaccharide and rhizodepositions associated with it.

The complementary effect of the fibrous and tap root system of C – M appear to underscore the higher porosity at the 15 – 30 cm depth. This accords with the observation of Aziz *et al*. (2011) that total porosity was greater under maize-soybean rotation continuous maize.

Total porosity was also mostly higher under mulching (+R) with significant impact recorded at the 0 – 15 and 15 – 30 cm depths in 2013 and 2014 respectively. The mulch presumably protected the soil against raindrop impact and its soil particle dispersion and pore clogging action, and thereby maintained the macroporosity of the soil through controlling surface crusting and sealing. Mulching has often been found to be associated with intensive earthworm activity which results in the creation of biopores. This could have contributed to the higher porosity recorded under mulching. Blanco-Canqui *et al*. (2006) reported that biopores created by earthworms was higher under mulch than nomulch.

The impact of factor interactions on soil physical properties have not received much research attention yet, this study has amply demonstrated that it is important. The tillage x crop rotation x mulch significantly influenced total porosity. The implication is that the magnitude of the impact of the interaction factors depend on each other. Thus, whereas the differences in the main effect of a factor, such as crop rotation at the 0 – 15 cm depth, on total porosity was not significant, it became significant as it interacted with tillage and mulching.

The importance of high porosity in crop production is well acknowledged. It increases soil infiltrability, enhances aeration and internal drainage, offers less impedance to root penetration and favours the moisture and nutrient availability of the soil. Runoff and erosion are also reduced to a minimum. However, it has been observed that as total porosity of the soil is reduced as a result of compaction, pore size distribution shifts toward smaller pore size and pore space continuity decreases (Sands *et al*., 1979). These adversely affect the soil as a medium for plant growth through reduction in water movement and availability, and aeration.

4.7.0 The impact of tillage, crop rotation, mulching and their interactions on aggregate size distribution and stability

4.7.1 Results

The results of the impact of tillage, crop rotation, mulching and their interactions on aggregate size distribution and stability are presented in Table 4.7a and 4.7b for dry sieving, and Table 4.7c and 4.7d for wet sieving.

The results of the dry sieving at the 0 – 15 cm depth (Table 4.7a) showed tillage to significantly ($P < 0.05$) influence aggregate stability and size range of 4 – 2 mm and < 0.25

mm. Whilst CT – NT recorded greater aggregates in the 4 – 2 mm size range and stability than CT – CT, the latter significantly (P < 0.05) has greater sizes in the range of < 0.25 mm.

Crop rotation, mulching and factor interactions also had significant (P < 0.05) effects on aggregate stability and all sizes. The impact of crop rotations on the various aggregate size range was not consistent but ranked as C – M > M – M > C – C in their impact on aggregate stability with values of mean weight diameter (MWD) ranging from 0.59 to 0.90 mm.

Mulching, on the other hand, consistently and significantly (P < 0.05) produced greater aggregates in all size ranges and stability than no-mulch. The magnitude of aggregate stability and sizes was also significantly (P < 0.05) influenced by the tillage x crop rotation x mulching interaction. The trend varied under the different size ranges. Aggregate stability as affected by the treatment interactions ranged from 0.47 to 0.98 mm under CT

– CT/C – C/-R and CT – CT/C – M/+R. Higher values in the ranged of 0.95 to 0.98 were recorded under interactions incorporating mulching, M – M and C – M. These were CT – CT/M – M/+R, CT – CT/C – M/+R, CT – NT/M – M/+R and CT – NT/C – M/+R.

At the 15 – 30 cm depth, the dry sieving results (Table 4.7b) showed CT – NT to significantly record greater aggregate sizes in the 4 – 2 mm and < 0.25 mm ranges than CT – CT, whilst the latter recorded significantly (P < 0.05) higher aggregate stability and sizes in the range of 1 – 0.25 mm.

The impact of crop rotation, mulching and the treatment interactions was significant (P < 0.05) on all aggregate size ranges and stability. Whilst the impact of crop rotation on aggregate stability followed a decreasing trend of C – M > M – M > C – C, with values ranging from 0.62 to 0.79 mm, it varied under the different size ranges as observed at the 0 - 15 cm depth. At both depths, the highest values under the < 0.25 mm and 1 – 0.25 mm size ranges were recorded under C – C and C – M respectively.

The impact of mulching showed aggregate stability, the size ranges of 4 – 2 mm, 2 – 1 mm and 1 – 0.25 mm being higher ($P < 0.05$) under mulching than no-mulch, whilst the latter produced higher aggregate size in the < 0.25 mm range. As observed at the 0 – 15 cm depth, the significant impact of the interactions on the different aggregate size ranges followed no consistent trend. In the case of aggregate stability, mean weight diameter (MWD) ranged from 0.55 to 0.92 mm under CT – CT/C – C/-R and CT – NT/C – M/+R respectively. The same trend of interactions involving M – M, C – M and +R recording higher aggregate stability at the 0 – 15 cm depth was observed at the 15 – 30 cm depth with values ranging from 0.81 to 0.92 mm.

The results of the wet sieving showed tillage, crop rotation, mulching and their interactions to significantly ($P < 0.05$) influence aggregate size distribution and stability (Table 4.7c and 4.7d).

At the 0 – 15 cm depth (Table 4.7c), the percentage aggregates in the 4 – 2 mm, 2 – 1 mm and 1 – 0.25 mm and aggregate stability were higher under CT – NT than CT – CT. The latter recorded higher aggregates in the < 0.25 mm size range. Aggregate stability under the different crop rotation ranged from 0.59 to 0.83 mm in the order of M – M > C – M > C – C. The differences were significant ($P < 0.05$). Maize monoculture generally produced significantly higher macroaggregates than C – C as well as the 4 – 2 mm fraction under C

– M. On the other hand, significantly higher microaggregates (< 0.25 mm) was recorded under C – C than M – M and C – M.

Significantly higher (P < 0.05) aggregate stability and percentage distribution in the size ranges of 4 – 2 mm, 2 – 1 mm and 1 – 0.25 mm were observed under mulch than no-mulch which had higher values in the < 0.25 mm size range. The significant (P < 0.05) impact of interactions of aggregate size distribution followed the inconsistent trend reported earlier under the dry sieving results. Aggregate stability as influenced by the treatment interactions ranged between 0.57 to 0.90 mm under CT – CT/C – C/-R and CT – NT/M –

M /+R respectively. Higher values in the range of 0.80 to 0.91 mm were recorded under

CT – NT/M – M/-R < CT – NT/C – M/-R < CT – CT/M – M/+R < CT – NT/C – M/+R <

CT – NT/M – M/+R.
At the 15 – 30 cm depth (Table 4.7d), aggregate stability was similar under both CT – CT and CT – NT. Significant differences were observed only under the size range of 2 – 1 mm where higher values were recorded under CT - CT.

Aggregate stability under the crop rotations significantly (P <0.05) differed with a range of 0.57 to 0.80 mm and a trend of C – M > M – M > C – C. The trend of the impact of rotation under the various size ranges varied, with C – C recording the highest percentage distribution under < 0.25 mm.

The results further showed aggregate stability to be higher under mulching and size ranges of 4 – 2 mm, 2 – 1 mm and 1 – 0.25 mm than no-mulch which recorded higher percentage size distribution in the < 0.25 mm range. The factor interactions also significantly ($P < 0.05$) affected the aggregate stability and size distribution with variable trends under the different size ranges. Aggregate stability however ranged from 0.51 to 0.90 mm under CT – CT/C – C/-R and CT – CT/C – M/+R, respectively. Higher aggregate stability values ranging from 0.82 to 0.90 mm were recorded under CT – CT/M – M/+R, CT – NT/M – M/+R, CT – NT/C – M/+R and CT – CT/C – M/+R.

The results of both dry and wet sieving showed the percentage aggregate size distribution under treatments to follow a trend of 1 – 0.25 mm > < 0.25 mm > 2 – 1 mm > 4 – 2 mm.

Most of the aggregates therefore fell in the range of 1 – 0.25 mm with the least in the 4 – 2 mm range.

Table 4.7a. Aggregate size distribution and stability obtained by dry sieving at the 0 – 15 cm soil depth

Practice	Sieve size (mm)				
	4 - 2	**2 - 1**	**1 – 0.25**	**< 0.25**	
Tillage	**Aggregate size distribution (%)**				**MWD (mm)**
CT – CT	14.97	17.49	39.79	27.75	0.78
CT – NT	15.50	18.68	40.44	25.38	0.80
CV (%)	41.7	18.3	22.9	61.5	22.2
$LSD_{0.05}$	0.31	ns	ns	0.82	0.008
Crop rotation					
C – C	9.17	14.88	31.19	44.76	0.59
M – M	18.91	19.88	42.26	18.95	0.87
C – M	17.63	19.50	46.89	15.99	0.90

CV (%)	29.4	13.3	15.2	34.3	12.4
$LSD_{0.05}$	0.79	0.64	1.35	0.69	0.007
Mulching					
-R	11.52	16.39	38.99	20.03	0.72
+R	18.95	19.78	41.23	33.10	0.86
CV (%)	32.8	15.8	22.8	55.9	20.2
$LSD_{0.05}$	0.41	0.58	0.84	0.52	0.005
Interactions					
CT – CT/C – C/-R	5.36	14.05	24.26	56.33	0.47
CT– CT/ C-C/+R	10.90	16.67	24.91	47.51	0.56
CT– CT/M–M/-R	13.55	18.28	48.81	19.36	0.87
CT– CT/M–M/+R	21.80	18.91	48.12	11.16	0.95
CT– CT/C–M/-R	13.62	16.68	46.11	23.62	0.82
CT– CT/C–M/+R	24.61	20.35	46.49	8.54	0.98
CT – NT/C – C/-R	8.56	11.96	36.75	42.73	0.61
CT–NT/ C – C/+R	11.86	16.82	38.84	32.46	0.72
CT–NT/M–M/-R	15.29	18.28	31.90	34.52	0.70
CT–NT/M–M/+R	25.00	24.05	40.19	10.75	0.96
CT–NT/C–M/-R	12.76	19.12	46.13	22.03	0.84
CT–NT/C–M/+R	19.55	21.86	48.82	9.77	0.97
Mean	15.24	18.09	40.11	26.57	0.79
CV (%)	3.7	4.5	2.9	2.7	1.0
$LSD_{0.05}$	1.09	1.74	2.33	1.19	0.013

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference, MWD: mean weight diameter.

Table 4.7b. Aggregate size distribution and stability obtained by dry sieving at 15 – 30 cm soil depth

Practice	Sieve size (mm) 4 - 2	2 - 1	1 – 0.25	< 0.25	MWD (mm)
Tillage	Aggregate size and stability (%)				
CT – CT	13.32	15.87	39.90	30.91	0.74
CT – NT	14.31	16.25	34.95	34.49	0.70
CV (%)	26.6	18.9	18.0	34.1	16.6
$LSD_{0.05}$	0.39	ns	2.62	3.51	0.037
Crop rotation					
C – C	11.29	14.84	32.10	41.76	0.62
M – M	14.16	17.79	37.82	30.22	0.75
C – M	15.99	15.55	42.35	26.11	0.79
CV (%)	22.7	17.2	15.4	27.5	13.4
$LSD_{0.05}$	1.05	0.80	1.26	1.13	0.012
Mulching					
-R	11.46	14.59	34.05	39.96	0.64
+R	16.23	17.54	40.79	25.44	0.80
CV (%)	19.4	16.2	16.7	25.3	12.3
$LSD_{0.05}$	0.71	0.74	1.30	0.97	0.010
Interactions					
CT – CT/C – C/-R	8.66	15.14	27.25	48.95	0.55
CT– CT/ C-C/+R	12.53	17.24	38.84	31.39	0.74
CT– CT/M–M/-R	13.24	18.54	36.74	31.47	0.74
CT– CT/M–M/+R	17.44	16.65	44.86	21.06	0.85
CT– CT/C–M/-R	11.61	12.18	44.60	31.61	0.73
CT– CT/C–M/+R	16.44	15.48	47.10	20.98	0.85
CT – NT/C – C/-R	9.07	11.73	33.07	46.13	0.58
CT–NT/ C – C/+R	14.92	15.27	29.22	40.59	0.64
CT–NT/M–M/-R	10.74	16.90	28.47	43.89	0.60
CT–NT/M–M/+R	15.24	19.09	41.20	24.47	0.81
CT–NT/C–M/-R	15.06	13.05	34.18	37.71	0.67
CT–NT/C–M/+R	20.83	21.49	43.54	14.14	0.92
Mean	13.81	16.06	37.42	32.70	0.72
CV (%)	7.1	6.4	4.8	4.1	2.0
$LSD_{0.05}$	1.63	1.51	2.85	2.82	0.030

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained,

Table

ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference, MWD: mean weight diameter.

4.7c. Aggregate size distribution and stability obtained by wet sieving at 0 – 15 cm soil depth

	Sieve size (mm)				
Practice	**4 – 2**	**2 – 1**	**1 – 0.25**	**< 0.25**	**MWD (mm)**
Tillage	**Aggregate size distribution (%)**				
CT – CT	13.27	14.52	36.48	37.73	0.69
CT – NT	14.35	16.41	39.73	29.51	0.76
CV (%)	29.4	16.4	22.7	39.8	19.3
$LSD_{0.05}$	1.58	0.35	2.80	3.51	0.037
Crop rotation					
C – C	10.07	15.36	29.48	45.08	0.59
M – M	17.44	15.96	43.67	22.93	0.83
CV (%)	19.0	17.8	15.7	28.4	13.7
C – M	13.91	15.07	41.16	29.86	0.75
$LSD_{0.05}$	2.47	1.95	4.96	6.83	0.073
Mulching					
-R	12.69	13.58	36.62	37.10	0.67
CV (%)	28.5	12.0	22.8	38.4	18.6
+R	14.92	17.35	39.59	28.14	0.77
$LSD_{0.05}$	1.27	0.76	0.87	1.13	0.012
Interactions					
CT – CT/C – C/-R	8.66	13.15	31.43	46.75	0.57
CT– CT/ C-C/+R	10.45	17.66	34.67	37.23	0.67
CT– CT/M–M/-R	14.66	13.40	39.53	32.41	0.73
CT– CT/M–M/+R	20.59	16.17	45.00	18.24	0.88
CT– CT/C–M/-R	12.10	12.18	33.54	42.18	0.62
CT– CT/C–M/+R	12.14	14.57	34.71	37.58	0.67
CT – NT/C – C/-R	9.61	13.39	24.72	52.24	0.51
CT–NT/ C – C/+R	11.55	17.25	27.12	44.07	0.60
CT–NT/M–M/-R	15.15	14.81	44.22	25.82	0.80
CT–NT/M–M/+R	19.37	19.46	45.93	15.24	0.91
CT–NT/C–M/-R	15.98	14.55	50.08	23.17	0.82

Table

Mean	13.81	15.46	38.10	32.62	0.72
CV (%)	12.7	6.8	3.2	4.8	2.3
$LSD_{0.05}$	3.44	2.48	5.91	8.09	0.087
CT–NT/C–M/+R	14.44	18.97	46.30	16.51	0.90

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference, MWD: mean weight diameter.

4.7d. Aggregate size distribution and stability obtained by wet sieving at 15 - 30 cm soil depth

	Sieve size (mm)				
	Aggregate size distribution (%)				
Practice	**4 – 2**	**2 – 1**	**1 – 0.25**	**< 0.25**	**MWD (mm)**
Tillage					
CT – CT	13.49	17.81	35.02	33.68	0.71
CT – NT	14.91	14.50	36.30	34.29	0.71
CV (%)	41.0	24.6	14.8	35.9	18.5
$LSD_{0.05}$	ns	2.47	ns	ns	ns
Crop rotation					
C – C	7.91	12.56	32.81	46.72	0.57
M – M	16.68	17.30	36.82	29.20	0.76
C – M	18.01	18.60	37.35	26.04	0.80
CV (%)	24.6	21.2	13.9	22.3	11.5
$LSD_{0.05}$	3.49	2.70	5.58	3.83	0.040
Mulching					
-R	12.47	14.63	33.48	39.43	0.65
+R	15.93	17.68	37.85	28.54	0.77
CV (%)	39.2	25.0	13.4	31.6	16.3
$LSD_{0.05}$	0.99	1.76	1.12	2.38	0.026
Interactions					
CT – CT/C – C/-R	5.62	12.49	28.99	52.91	0.51
CT– CT/ C-C/+R	7.16	14.13	33.31	45.40	0.59
CT– CT/M–M/-R	14.31	16.63	23.08	35.98	0.69
CT– CT/M–M/+R	17.29	21.27	37.57	23.86	0.82
CT– CT/C–M/-R	16.77	19.24	36.93	27.07	0.79

Table

Mean	14.20	16.15	35.66	33.99	0.71
CV (%)	9.6	15.0	4.3	9.7	5.0
$LSD_{0.05}$	6.30	4.21	9.60	7.07	0.070
CT– CT/C–M/+R	19.79	23.09	40.27	16.85	0.90
CT – NT/C – C/-R	8.06	10.23	33.63	48.08	0.56
CT–NT/ C – C/+R	10.80	13.39	35.32	40.49	0.64
CT–NT/M–M/-R	16.27	13.49	36.82	33.42	0.72
CT–NT/M–M/+R	18.84	17.79	39.83	23.55	0.82
CT–NT/C–M/-R	13.79	15.67	31.41	39.13	0.66
CT–NT/C–M/+R	21.71	16.40	40.79	21.10	0.85

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference, MWD: mean weight diameter.

4.7.2 Discussion

Soil aggregates can be grouped by their mode of formation as the association of clay particles into domains (approximately 5 µm; 0.005 mm), domains and silt particle into microaggregates (< 250 µm; < 0.25 mm) and microaggregates and sand particles into macroaggregates (> 250 µm; > 0.25 mm) each of them bound by different binding agents (van Donk *et al*., 2012).

The macroaggregates owe their stability to binding agents such as plant roots and associated hyphae, which are temporary and easily affected by soil management and decompose within months. The microaggregates are stabilized by transient and persistent binding agents exemplified respectively by polysaccharides and degraded humic material associated with amorphous iron and aluminium (Six *et al*., 2002). Within the microaggregates the clay-humic interactions constitute a stable unit largely independent of soil management. Organic matter is thus considered to be the single most important factor determining structural stability in topsoils. Any factor which affects these binding agents do influence the magnitude of aggregate stability.

The study showed that tillage, crop rotation and mulching significantly affected both aggregate size distribution and stability. Continuous conventional tillage practice (CT – CT) recorded a greater percentage of aggregates in the microaggregate size range (< 0.25 mm) and lower aggregate stability than CT – NT. Even, in the macroaggregate size range, the latter was noted for the higher end of range. The underlying reasons may be ascribed to the relative magnitude of soil disturbance and organic carbon content associated with the CT – CT and CT – NT practices. In the former case, tillage is accomplished by enhanced soil disturbance and pulverization of soil into smaller aggregates. It is also often accompanied by high organic matter decomposition and low soil organic carbon content. The latter, on the other hand had less wheel traffic, soil disturbance and higher soil organic carbon. The positive correlation of soil organic carbon (SOC) with aggregate stability shown by the results of the study (Appendix 20) imply that, the tillage practice with higher SOC as recorded under CT – NT, would have more stable aggregates than CT – CT.

The results showed C – M and M – M with greater aggregate stability and percentage aggregates in the macro size range (> 0.25 mm) than C – C which had more of the microaggregates. Aggregate stability and size distribution are thus significantly influenced by the crop type and sequence.

The role of root biomass, its attributes in aggregate formation and stability, contribution to SOC, organic cementing agents and soil water extraction potential (wetting and drying cycles) are all important considerations in these observations. Observations made in this study, six weeks after sowing, showed the dry root biomass of maize to be 90.07 % greater than that of cowpea at the 0 – 15 cm depth (Appendix 26). A similar observation was reported by Adiku *et al*. (2008). Besides, contributing to increased SOC, maize roots are also known to produce exudates which instantaneously bind soil aggregates (Six *et al*., 2004). Thus monocrop maize and legume systems in rotation, such as C – M, tend to enhance aggregate stability more than continuous monocrop cowpea. The higher fraction of microaggregates under C – C may be due to the lower recorded SOC with its implicit reduced production of binding agents. This could be alluded to the lower root biomass and its higher quality and associated rapid decomposition. The results accord with the observed

association of the high fraction of microaggregates with low carbon content reported by Six *et al*. (2000), Curaqueo *et al*. (2010), and Devine *et al*. (2014).
The results have shown that macroaggregation of a sandy loam can be increased under a cowpea-maize rotation relative to continuous monocrop cowpea. On the other hand, continuous monocrop maize tend to retain higher fraction of large-sized macroaggregates under wet than dry sieving.

Besides tillage and crop rotation, mulching significantly influenced the magnitude of aggregates stability and size distribution. Higher aggregate stability and a greater fraction of soil macroaggregates were recorded in the top 0 – 15 cm under mulch than no mulch (Table 4.7a and 4.7c). These observations may be ascribed to the fact that the mulch protected the soil against the disintegrating impact of raindrops produced a higher SOC content and enhanced soil microbial activities. The latter activities especially of fungi, have been found to enhance macroaggregation by their hyphae (Devine *et al*., 2014). According to Zhang *et al*. (2014), a higher fraction of fungi and bacteria were found in aggregate sizes > 0.25 mm and < 0.25 mm respectively.

The results further showed that the magnitude of the impact of tillage, crop rotation and mulching on aggregate size distribution and stability depended on each other as indicated by the significant interaction of the factors. The results showed that all tillage rotations (CT – CT and CT – NT) combined with mulching, continuous maize (M – M) and cowpeamaize (C – M) rotation increased aggregate stability more than any other combinations. Although, the trend in the impact of the interactions under the various aggregate size ranges was not consistent, the tendency of enhanced macroaggregation was observed under all tillage practices incorporating mulching and cowpea-maize rotation. The results amply demonstrated the complementary role of the interacting factors.

4.8.0 The impact of tillage, crop rotation, mulching and their interactions on the hydro-physical properties of the soil

4.8.1 Results

4.8.1.1 Saturated hydraulic conductivity

The results of saturated hydraulic conductivity are presented in Table 4.8.1. Tillage practice significantly ($P < 0.05$) influence Ks, with CT – CT recording a lower value than the CT – NT. On the other hand, Ks varied significantly ($P < 0.05$) among the different crop rotations and mulching, and the variation followed the trend M – M > C – M > C – C under the former and in the latter case, mulch recorded lower value than no-mulch. The interaction of tillage x crop rotation x mulching significantly ($P < 0.05$) affected Ks. The interactions involving CT – CT tended to give higher values than those with CT – NT. The highest Ks values were recorded under CT – CT/M – M/+R and CT – NT/C – M/-R, respectively. The correlation analysis showed Ks to be positively correlated with total porosity and organic matter but negatively correlated with bulk density and penetration resistance.

4.8.1.2 Sorptivity, steady state infiltrability and cumulative infiltration amount

The results of tillage, crop rotation, mulching and their interactions impact on sorptivity

(S), steady state infiltrability (K_o) and cumulative infiltration amount (I) are presented in Table 4.8.2.

Tillage did not significantly influence sorptivity. However, the magnitude of sorptivity under CT – NT was 48 % greater than that of CT – CT. Steady state infiltrability was also similar under the tillage treatments. However, significantly ($P < 0.05$) higher cumulatively infiltration amount was recorded under CT – NT than CT – CT with the former being 31 % greater.

Table 4.8.1 Effect of tillage, crop rotation and mulching on saturated hydraulic conductivity

Practice			
Tillage	**Ks (cm h^{-1})**	**Interactions**	**Ks (cm h^{-1})**
CT – CT	7.51	CT- CT/C – C/-R	8.64
CT - NT	12.28	CT–CT/ C-C/+R	9.50
CV (%)	28.0	CT–CT/M–M/-R	13.60 16.74
$LSD_{0.05}$	1.87	CT–CT/M–M/+R	14.74
Crop rotation		CT–CT/C–M/-R	10.20
C – C	9.08	CT–CT/C–M/+R	7.74
M – M	11.09	CT- NT/C – C/-R	10.44
C – M	9.45	CT–NT/ C-C/+R	6.48 7.56
CV (%)	37.2	CT–NT/M–M/-R	5.40
$LSD_{0.05}$	1.35	CT–NT/M–M/+R	7.44
Mulching		CT–NT/C–M/-R	
-R +R	10.31	CT–NT/C–M/+R	
	9.44	Mean	9.87 14.2
CV (%)	37.5	CV (%)	2.36
$LSD_{0.05}$	ns	$LSD_{0.05}$	

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Cropping systems and mulching, however significantly ($P < 0.05$) affected the magnitude of all the three measured parameters. Sorptivity was ranked C – M > M - M > C – C with a range of 50.1 to 89.6 mm $s^{-1/2}$. The difference between C – M and C – C was significant ($P < 0.05$). Significantly ($P < 0.05$) higher sorptivity was recorded under mulch than nomulch.

The significant impact of tillage x crop rotation x mulching on sorptivity is indicative of the dependence effect of the factors on each other with higher values being recorded under CT – NT/ C – M/+R, CT – NT/M – M/+R and CT – NT/C – M/-R.

Table 4.8.2 Effect of tillage, crop rotation and mulching on infiltration

Practice	Cumulative infiltration amount (mm)	Sorptivity (mm $s^{-1/2}$)	Steady state infiltrability (mm s^{-1})
Tillage			
CT – CT	920	49.6	0.23
CT – NT	1338	96.1	0.26
CV (%)	59.0	54.0	43.2
$LSD_{0.05}$	401.8	ns	ns
Cropping system			
C – C	760	50.1	0.18
M – M	1060	78.9	0.23
C – M	1567	89.6	0.32
CV (%)	54.6	59.9	36.5
$LSD_{0.05}$	188.1	12.34	0.02
Mulching			
-R	774	57.9	0.20
+R	1485	87.8	0.29
CV (%)	52.6	59.9	39.5
$LSD_{0.05}$	156.1	15.80	0.02
Interactions			
CT – CT/C – C/-R	377	24.7	0.19
CT – CT/C – C/+R	1152	59.4	0.24
CT – CT/M – M/-R	568	43.9	0.22
CT – CT/M – M/+R	1032	62.1	0.23
CT – CT/C – M/-R	1144	68.1	0.25
CT – CT/C – M/+R	1249	39.7	0.24
CT – NT/C – C/-R	807	65.9	0.14
CT – NT/C – C/+R	706	50.3	0.16
CT – NT/M – M/-R	693	61.5	0.14
CT – NT/M – M/+R	1947	148.2	0.32
CT – NT/C – M/-R	1054	83.5	0.27

CT – NT/C – M/+R	2823	167.1	0.53
Mean	1129	72.9	0.24
CV (%)	19.0	29.9	10.3
$LSD_{0.05}$	384	39.20	0.04

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Steady state infiltrability under the cropping system was in an increasing order of C – C < M – M < C – M with a range of 0.18 to 0.32 mm $s^{-1/2}$ (that is, 64.8 to 115.2 cm h^{-1}). Mulching also had significantly ($P < 0.05$) higher steady infiltration rate than no-mulch. Steady state infiltrability was also significantly impacted upon by the tillage x crop rotation x mulching interaction following the order, CT – NT/C – M/+R > CT – NT/M – M/+R > CT – NT/C – M/-R.

Cumulative infiltration amount ranged from 760 m to 1567 mm in the same order as steady state infiltrability. Cumulative infiltration amount was also significantly higher under mulching than no-mulching. The interaction of tillage x crop rotation x mulching significantly ($P < 0.05$) affected the magnitude of cumulative infiltration amount with higher values recorded under CT – NT/C – M/+R, CT – NT/M – M/+R and CT – CT/C – M/+R in that order and a range of 1249 to 2823 mm.

4.8.2 Discussion

Hydraulic conductivity, sorptivity and infiltrability are among the major hydro-physical properties of the soil that affect its water intake, flow, storage, deep percolation and recharge of groundwater as well as onset of overland flow.

4.8.2.1 Saturated hydraulic conductivity

The saturated hydraulic conductivity of the soil is a major indicator of the soil's ability to transmit water to the root zone and drain excess water to recharge the groundwater. It is influenced by several factors including soil texture, compaction, aggregate stability, bulk density, porosity and pore size distribution and soil organic carbon. Soil and crop management practices that adversely affect any of these factors could similarly influence the magnitude of Ks.

The results of the study showed Ks to be significantly influenced by crop rotation and tillage with continuous conventional tillage (CT – CT) producing lower Ks than the conventional-no-till rotation (CT – NT) and a trend of M – M > C – M > C – C for crop rotation. Although mulching affected Ks, the differences in the values among the treatments were not significant. However, its interaction with tillage and crop rotation yielded significant differences. The complementary impact of CT – CT and M – M, C – M on mulching (+R) was greater than that of the CT – NT with their respective interaction

Ks values ranging from 10.2 to 16.74 cm h^{-1} and 5.40 to 7.44 cm h^{-1}. The observed lower Ks under CT – CT was ascribed to its higher bulk density due to compaction, greater penetration resistance, lower total porosity and soil organic carbon since these parameters correlated negatively with Ks. The higher Ks under the M – M could be due mainly to its greater porosity than the other rotations.

Nevertheless, there appears to be a controversy about the impact of conventional tillage and no-tillage on saturated hydraulic conductivity. Some authors have reported higher Ks values under conventional tillage than no-tillage attributing it to improved porosity under the former (Nicou and Charreau, 1985; Zougmoré *et al*., 2004) and compaction under the latter

(Bhattacharyya *et al*., 2006). Others recorded higher Ks values under no-tillage than conventional tillage (Osunbitan *et al*., 2005; Capowiez *et al*., 2009; Sauwa *et al*., 2013a) and alluded it to better soil hydraulic characteristics due to maintenance of soil structure and hydraulically functioning pores (Govaerts *et al*., 2007; Ouattara, 2007).

In contributing to this discourse, the results of this study suggest that, on compacted soils, an initial loosening of the soil by conventional tillage prior to the commencement of the continuous no-tillage would facilitate the achievement of the optimum benefits of the latter practice. Additionally, this would provide similar soil conditions for a more meaningful comparison of subsequent impacts of continuous conventional tillage (CT – CT) and no-tillage (CT – NT).

The Ks values recorded were within the range of 1 – 15 cm h^{-1} considered suitable for most agricultural production practices by Brady and Weil (2002). Lower values may result in decreased water flow in the soil which can have adverse impact on soil water storage and uptake by plant roots, as well as the growth and yield of crops (Hillel, 1998).

4.8.2.2 Sorptivity

Sorptivity is a measure of the capacity of the soil to absorb or desorb water by capillarity without gravitational effects (Philip, 1957). It is used to evaluate the overland flow potential of the soil since it is related to time-to-incipient ponding, defined as the transition between preponding and ponding during infiltration into unsaturated soil.

The results of the study showed sorptivity to be higher under CT – NT than CT – CT and under mulching than no-mulch. The trend under crop rotation was C – M > M – M > C – C.

In an attempt to find the reasons underlying this observation, the correlation of sorptivity with other measured parameters was examined. The results showed sorptivity to be positively and highly significant in correlation with total porosity, soil organic carbon, aggregate stability, hydraulic conductivity, steady state infiltrability and cumulative infiltration (Table K and Table L). The implication is that sorptivity increases as the magnitude of these parameters increase. It is therefore not surprising that the treatment with the higher values of these parameters recorded higher sorptivity.

It is, however, instructive to point out that whilst the impact of total porosity is important in processes such as sorptivity, infiltration, hydraulic conductivity and water storage, pore size, distribution and continuity exert the most significant impact. The tendency is a decrease in sorptivity with increasing pore size due to its greater dependence on matric suction than gravitational force (Hillel, 1998; Hallett, 2008; Serme, 2014). The higher values of sorptivity imply that ponding of water under these treatments takes a longer time to occur during rainfall and thereby allow more water intake for storage in the soil. Under such circumstances, runoff and erosion are reduced and rainwater is optimized for crop production. Practices such as CT – NT, mulching and C – M therefore present favourable conditions for enhanced and sustained agricultural productivity under the rainfed agriculture of smallholder farmers. The significant interaction of these factors imply that the soil conditions for crop production become even better when these factors are integrated.

4.8.2.3 Infiltration

The main source of water for crop production in rainfed smallholder agriculture is soil moisture. Optimizing rainwater usage for crop production therefore requires the soil to be managed to facilitate as much water intake to fill the soil reservoir through improved infiltrability and ensuring that the water is effectively and efficiently used by reducing the non-productive evaporation from bare surfaces and weeds. The results showed tillage, crop rotation, mulching and their interaction to significantly influence the steady state and cumulative infiltration amount (Table 4.8.2). The results further showed these parameters to be significantly and positively correlated with total porosity, sorptivity, aggregates stability and soil organic carbon. This implies that practices with greater values of these parameters than others will record higher steady state infiltrability and cumulative infiltration amount as observed under CT – NT, C – M, M – M and mulching (+R).

In this study, a one-time conventional tillage followed subsequently by no-tillage increased total amount of water intake and showed a greater tendency to reduce surface runoff through its higher steady state infiltrability. No-tillage practice facilitates the preservation, connectivity and continuity of biopores. These pores serve as preferential flow paths for efficient and effective water infiltration unlike under CT – CT where soil mixing and disturbance cause collapse, disconnection and discontinuity of pores.

On the other hand, crop diversification and mulching outperformed monoculture and nomulch respectively in their impact on water infiltration. The results also showed that M – M significantly increased water infiltrability and cumulative infiltration than C – C. The superior water uptake by the soil under C – M and +R could be attributed to the reduced surface compaction, improved soil structure (through enhanced aggregation), and a higher tendency for increased soil-water contact time. The implicit benefits of these practices on soil management include increased soil water content, reduced wetting and drying cycles, and increased moisture availability for crop growth especially during dry season crop production.

The results further showed significant effect of tillage x crop rotation x mulching on infiltrability and cumulative infiltration amount. Significantly higher values were noticed under CT – NT/C – M/+R and CT – NT/M – M/+R, which also showed complementary treatment interaction. Therefore, the magnitude of the complementary effect depends on the type and level of the interacting factors.

4.9.0 The impact of tillage, crop rotation, mulching and their interactions on soil moisture storage.

4.9.1 Results

The results of tillage, crop rotation, mulching and their interactions on soil moisture storage and cumulative moisture storage are presented in Table 4.9a and 4.9b, and 4.9c respectively.

In 2013 (Table 4.9a), CT – CT and CT – NT had no significant differences in their soil moisture storage at the 0 – 15 cm and 15 – 30 cm depths. However, in 2014 (Table 4.9b), the differences in the magnitude of soil moisture storage were significant ($P < 0.05$) at both soil depths. Whilst CT – CT recorded higher moisture storage than CT – NT at the 0 – 15 cm depth, the latter had a higher value at the 15 – 30 cm depth.

Soil moisture storage under the various crop rotation did not differ significantly at both depths. However, there was a tendency for higher moisture storage at the 15 – 30 cm than the 0 – 15 cm depth particularly in 2014 with the differences under both M – M and C – M being significant.

Mulching, generally recorded higher moisture storage than no-mulch in both 2013 and 2014 although the differences were not significant in 2013. In 2014, significant ($P < 0.05$) differences were observed at the 0 – 15 cm depth, and between the 0 – 15 cm and 15 – 30 cm depths under both mulching and no-mulching. Soil moisture storage also tended to be higher at the 15 – 30 cm than the 0 – 15 cm depth.

Table 4.9a Effect of tillage, crop rotation, mulching and their interactions on soil moisture storage in 2013 cropping season

	Soil moisture storage (mm)			
	Soil depth (cm)			
Practice	0 – 15	15 – 30	CV (%)	$LSD_{0.05}$
Tillage				
CT – CT	15.36	15.15	24.9	ns
CT – NT	15.20	16.05	15.2	ns
CV (%)	22.4	18.9		
LSD	ns	ns		
Crop rotation				
C – C	13.78	15.41	14.8	ns
M – M	16.01	16.45	27.7	ns
C – M	16.05	14.94	14.0	ns
CV (%)	21.5	19.0		
LSD0.05	ns	ns		
Mulching				
-R	14.20	14.72	16.4	ns
+R	16.36	16.48	21.7	ns
CV (%)	21.1	18.2		
LSD0.05	ns	ns		
Interactions				
CT – CT/C – C/-R	15.00	16.37	2.2	1.20
CT– CT/ C-C/+R	11.20	12.71	4.1	ns
CT– CT/M–M/-R	11.60	14.70	19.4	ns
CT– CT/M–M/+R	21.60	18.20	12.6	ns
CT– CT/C–M/-R	16.81	12.40	10.4	ns

CT– CT/C–M/+R	16.00	14.95	10.2	ns
CT – NT/C – C/-R	14.16	16.64	14.1	ns
CT–NT/ C – C/+R	14.74	15.93	10.2	ns
CT–NT/M–M/-R	12.70	13.50	21.7	ns
CT–NT/M–M/+R	18.23	17.81	4.2	ns
CT–NT/C–M/-R	14.97	14.74	3.3	ns
CT–NT/C–M/+R	16.44	17.66	3.2	ns
Mean	15.28	15.47		
CV (%)	14.0	12.1		
LSD0.05	3.63	3.15		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Table 4.9b Effect of tillage, crop rotation, mulching and their interactions on soil moisture storage in 2014 cropping season

	Soil moisture storage (mm)			
	Soil depth (cm)			
Practice	0 - 15	15 - 30	CV (%)	$LSD_{0.05}$
Tillage				
CT – CT	21.50	22.80	29.0	ns
CT – NT	14.11	28.16	20.1	2.87
CV (%)	31.8	20.1		
LSD	3.83	3.47		
Crop rotation				
C – C	19.70	22.30	35.8	ns
M – M	15.94	26.70	18.8	3.42
C – M	17.70	27.40	29.5	5.67
CV (%)	38.1	21.3		
LSD0.05	ns	ns		
Mulching				
-R	15.52	24.59	21.7	2.96
+R	20.00	26.36	32.2	5.07
CV (%)	36.2	22.7		
LSD0.05	4.37	ns		
Interactions				
CT – CT/C – C/-R	19.70	20.90	15.7	ns
CT– CT/ C-C/+R	26.00	17.60	26.8	ns
CT– CT/M–M/-R	16.80	24.60	23.5	ns

CT– CT/M–M/+R	19.00	24.60	24.4	ns
CT– CT/C–M/-R	17.85	23.73	8.7	ns
CT– CT/C–M/+R	26.00	25.30	39.0	ns
CT – NT/C – C/-R	15.49	20.10	10.3	ns
CT–NT/ C – C/+R	14.45	30.48	2.7	2.13
CT–NT/M–M/-R	11.58	28.12	9.7	6.73
CT–NT/M–M/+R	16.40	29.50	13.7	11.06
CT–NT/C–M/-R	11.70	33.40	35.1	ns
CT–NT/C–M/+R	15.00	30.60	30.9	ns
Mean	17.50	25.64		
CV (%)	22.8	19.1		
LSD0.05	6.76	8.28		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Table 4.9c Tillage, crop rotation and mulching impact on cumulative moisture storage

	Cumulative moisture storage (mm)			
	Year			
Practice	**2013**	**2014**	**CV (%)**	**$LSD_{0.05}$**
Tillage				
CT – CT	30.51	44.20	18.1	4.75
CT – NT	31.25	42.31	11.3	2.91
CV (%)	18.2	14.6		
$LSD_{0.05}$	ns	ns		
Crop rotation				
C – C	29.19	42.01	19.1	6.12
M – M	32.47	42.62	13.7	4.62
C – M	30.99	45.11	12.6	4.31
CV (%)	17.9	14.7		
$LSD_{0.05}$	2.39	ns		
Mulching				
-R	28.92	40.12	11.0	2.66
+R	32.84	46.43	17.7	4.92
CV (%)	16.9	12.7		
$LSD_{0.05}$	2.88	4.81		
Interactions				
CT – CT/C – C/-R	31.37	40.62	12.2	ns
CT– CT/ C- C/+R	23.92	46.92	26.0	ns

CT– CT/M–M/-R	26.24	41.40	9.5	11.31
CT– CT/M–M/+R	41.38	43.63	12.6	ns
CT– CT/C–M/-R	29.21	41.60	10.2	ns
CT– CT/C–M/+R	30.95	51.41	10.3	14.89
CT – NT/C – C/-R	30.80	35.61	7.1	ns
CT–NT/ C – C/+R	30.67	44.93	7.7	10.16
CT–NT/M–M/-R	26.21	39.70	12.5	ns
CT–NT/M–M/+R	36.04	45.92	9.6	ns
CT–NT/C–M/-R	29.70	41.84	7.0	8.85
CT–NT/C–M/+R	34.10	45.71	17.6	ns
Mean	30.88	43.3		
CV (%)	12.8	15.3		
$LSD_{0.05}$	6.32	9.77		

CT – CT is continuous conventional tillage, CT – NT is tillage rotation, C – C is cowpea monoculture, M – M is maize monoculture, C – M is cowpea-maize rotation, -R is no residue mulch, +R is residue mulch retained, ns: not significant at F probability 0.05, CV is coefficient of variation and LSD is least significant difference.

The tillage x crop rotation x mulch effected significant ($P < 0.05$) differences in soil moisture storage at both depths. At the 0 – 15 cm depth, higher moisture storage was recorded under CT – CT/C – M/+R and CT – CT/M – M/+R whilst CT – NT/C – M/+R and CT – NT/C – M/-R had higher values at the 15 – 30 cm depth.

In Table 4.9c, cumulative moisture storage tended to depict an increasing trend with time. That is, higher values were recorded in 2014 than in 2013.

The impact of tillage practice on cumulative moisture storage did not differ significantly in both years of study. Meanwhile, the values recorded were inconsistent between CT –

CT and CT – NT with CT – NT recording higher cumulative infiltration in 2013 and CT – CT in 2014.

Crop rotation and mulching significantly differed in their impact on cumulative moisture storage. Significant differences among cropping systems was noticed in 2013 but not 2014 with values following a trend of M – M > C – M > C – C in the previous year and C – M > M – M > C – C in the latter year. Mulching however, recorded significantly higher values in both years than no-mulch.

Treatment interactions, tillage x crop rotation x mulching significantly influenced cumulative moisture storage. Generally, treatment interactions with mulching increased cumulative moisture storage than without mulch. Complementary treatment effects was noticed under CT – CT/M – M /+R, CT – NT/M – M/+R and CT – NT/C – M/+R in 2013 and CT – CT/C – C/+R, CT – NT/M – M/+R and CT – NT/C – M/+R in 2014.

4.9.2 Discussion

Soil surface and structural characteristics, amount and intensity of rainfall are important determinants of the amount of water that infiltrates the soil and stored at the root zone. Therefore under rainfed agriculture, moisture stored by the soil is critical for ensuring uniform seed germination, plant growth, development and yield. Consequently, crop management practices that increase soil infiltrability could reduce surface runoff and erosion, enhance moisture storage and promote crop production.

In this study, higher soil moisture was consistently stored in the 0 – 15 cm than 15 – 30 cm depth under CT – CT. On the contrary, CT – NT increased moisture stored in the 15 – 30 cm than 0 – 15 cm depth. The moisture stored was significantly different between tillage practices at both depths and within treatments in the 15 – 30 cm depth in 2014 but not in

2013. Notwithstanding, cumulative moisture storage was not significantly different among tillage practices in both years of study.

In 2014, significant differences in moisture stored between soil depths within tillage practice was noticed in the 15 – 30 cm depth with the same depth recording higher values than the 0 – 15 cm. On the other hand, while significantly higher soil moisture was stored in the 0 – 15 cm depth under CT – CT, CT – NT significantly increased soil moisture in the 1 5 – 30 cm depth and showed a consistent tendency to increase moisture storage at deeper soil layer compared to CT – CT. The observation suggests that CT – NT was more likely to increase water stored at the root zone of plants thereby increasing water availability for crop growth and yield. Thus, the higher moisture at deeper soil layer could be attributed to higher infiltration amount, positive soil structural changes and lower bulk density at the top 0 – 15 cm depth. A match of values in the study showed moisture storage to be positively correlated with cumulative infiltration amount and mean weight diameter while its relation with bulk density was negatively correlated (Appendix 20). This gives an indication that lower bulk density at the 0 – 15 cm depth facilitated higher infiltration and increased water stored at lower depth. The implication is that practices that increased bulk density at the 0 – 15 cm depth may decrease the tendency for higher moisture storage at lower soil depth. This is because denser soils tend to contain higher micropores which are moisture retention pores, hence the higher moisture stored at high bulk density. Consequently, higher moisture at the top 0 – 15 cm depth under CT – CT may limit moisture availability for plant uptake and growth, and increase unproductive loss while under CT – NT, increased moisture storage at lower depth could sustain plant growth through short-term drought periods, reduce rapid dry-wet cycles which alter soil structural stability and sustain fauna activity for longer periods.

Apart from tillage, cropping systems also influenced soil moisture storage. Moisture storage generally increased with depth with higher values at the 15 – 30 cm than 0 – 15 cm depth, yet, inter-treatment differences among crop rotation practices were not statistically significant. Meanwhile, significant differences in intra-treatment moisture storage was observable under M – M and C – M but not C – C in 2014. On the other hand, cumulative moisture storage differed significantly among cropping systems in 2013 with values following the trend, M – M > C – M > C – C. In 2014, the trend of cropping system impact on cumulative moisture storage was, C – M > M – M > C – C, though no significant differences existed among the treatments. The higher tendency for M – M and C – M to increase moisture storage could be alluded to the improved soil structure vis-à-vis higher mean weight diameter and soil organic matter content as associated with the greater fibrous root biomass and root diversity. Root diversity tends to increase the quality and quantity of SOC which aids in binding and stabilization of loose soil particles, and increases the inferred biopore distribution, connectivity and continuity which facilitate water infiltration into deeper horizons. The implication is that, cropping systems that increase these soil components also increase soil moisture and cumulative moisture storage.

Mulching generally increased soil moisture storage at both soil depths than no mulch with significant differences in cumulative moisture storage in 2013 and 2014. The greater influence of mulch on water infiltration and storage could be ascribed to the increased soil-water contact time, lower soil detachment and its pore clogging effect, and compaction. In addition are, reduced unproductive loss of moisture and improved soil structural condition. The cover provided by mulch tends to reduce splash erosion and runoff which transports detached and loose soil particles notable for clogging soil pores with a resultant effect of surface seals and crusts formation. These hinder infiltration and water storage while heightening compaction and its attended effects. Besides, mulch serves as a barrier and a basin or micro-dam to restrict water movement on the soil surface thereby allowing sufficient time for water infiltration and storage. Additionally, mulch creates a microclimate on the surface, which reduces the moisture gradient between the top and subsoil. This limits the tendency for moisture loss through capillary rise to satisfy the evaporative demand of the atmosphere. These benefits associated with mulch account for the higher moisture storage and cumulative moisture storage noticed under the

practice.

Tillage x crop rotation x mulching interactions especially in the case of CT – CT/M – M/+R, CT – NT/M – M/+R, CT – NT/C – M/+R and CT – CT/C – C/+R significantly impacted on moisture storage. These also showed complementary effect on cumulative moisture storage depending on the impact of the main factors involved in the interaction. The implication therefore is that, a combination of practices may affect soil condition more than individual practices and as in this case where higher moisture was stored.

4.10.0 The impact of tillage, crop rotation, mulching and their interactions on soil organic carbon

4.10.1 Results

The results of soil organic carbon (SOC) as affected by tillage, crop rotation, mulching and their interactions are presented in Table 4.10. Soil organic carbon decreased with soil depth and varied significantly between depths under each tillage practice. Generally, CT – NT recorded higher SOC in both 0 – 15 cm and 15 – 30 depths than CT – CT, however, significant difference was noticed only in the latter depth.

Crop rotation and mulching impact on soil organic carbon differed significantly between and within soil depths. In the 0 – 15 cm depth, SOC was significantly higher than 15 – 30 cm under these treatments. Soil organic carbon at both depths under crop rotation followed the trend, C – M > M – M > C – C. On the other hand, mulching significantly increased SOC than no-mulch.

Treatment interactions, tillage x crop rotation x mulching significantly influenced SOC at both depths with higher values recorded under interactions which included mulching and

CT – NT. Therefore, the results showed significantly higher and complementary treatment interaction effect under CT – NT/C – M/+R, CT – NT/M – M/+R and CT – NT/C – C/+R in both 0 – 15 cm and 15 – 30 cm depths.

Table 4.10 Effect of tillage, crop rotation and mulching on soil organic carbon

	Soil organic carbon (%)			
	Soil depth (cm)			
Practice	**0 – 15**	**15 – 30**		
Tillage			**CV (%)**	**$LSD_{0.05}$**
CT – CT	1.65	1.27	7.6	0.07
CT – NT	1.72	1.39	8.7	0.09
CV (%)	7.3	7.1		
$LSD_{0.05}$	ns	0.12		
Crop rotation				
C – C	1.65	1.26	10.5	0.13
M – M	1.68	1.34	8.9	0.11

C – M	1.72	1.38	7.1	0.09
CV (%)	7.5	7.8		
LSD0.05	0.03	0.05		
Mulching				
-R	1.59	1.25	7.7	0.07
+R	1.78	1.41	5.9	0.06
CV (%)	4.9	8.6		
LSD0.05	0.04	0.04		
Interactions				
CT – CT/C – C/-R	1.58	1.06	1.7	0.07
CT– CT/ C- C/+R	1.67	1.34	4.0	0.21
CT– CT/M–M/-R	1.57	1.20	2.5	0.11
CT– CT/M–M/+R	1.77	1.29	3.2	0.17
CT– CT/C–M/-R	1.57	1.30	5.0	0.25
CT– CT/C–M/+R	1.72	1.41	0.2	0.01
CT – NT/C – C/-R	1.52	1.19	1.8	0.08
CT–NT/ C – C/+R	1.80	1.45	6.4	ns
CT–NT/M–M/-R	1.54	1.43	0.3	0.01
CT–NT/M–M/+R	1.86	1.46	1.3	0.07
CT–NT/C–M/-R	1.74	1.36	2.4	0.13
CT–NT/C–M/+R	1.86	1.48	6.8	ns
Mean	1.68	1.33		
CV (%)	3.3	4.9		
LSD0.05	0.09	0.11		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

4.10.2 Discussion

Due to the enormous influence of soil organic carbon on soil quality, carbon loss tends to make the soil susceptible to degradation and decreased productivity. It is therefore important to identify crop production practices that sustain SOC rather than degrade it. The results of this study showed that tillage, crop rotation, mulching and their interactions affected the concentration of SOC in the soil.

Tillage significantly influenced soil organic carbon at the 15 – 30 cm depth under CT – NT which recorded higher values than CT – CT at both soil depths. The correlation of SOC with total porosity and saturated hydraulic conductivity under tillage practices showed a positive correlation whilst the correlation with bulk density was negative. Thus, as SOC increased, total porosity and saturated hydraulic conductivity increased while bulk density correspondingly decreased. The higher SOC under CT – NT therefore tended to improve soil aggregate stability, macropore formation and the hydro-physical properties. The tendency for higher SOC under CT – NT can be attributed to the reduction in soil disturbance, which slows carbon mineralization rate because of decreased population of aerobic bacteria and the accumulation of crop remains on and within the soil which is the main source of SOC. This agrees with the observation of Dorr de Quadros *et al*. (2012) who reported four-fold higher anaerobic microorganisms under no-till while conventional tillage recorded two-fold higher aerobic microorganisms. On the other hand, frequent soil mixing under CT – CT tends to expose SOC in soil aggregates to microbial attack and decomposition due to the pulverization of soil particles while the action of residue incorporation also increased direct microbial assess to organic matter for degradation. Finally, the loosening of the soil increases the tendency for carbon loss through surface erosion. The implication is that following conventional tillage with no-till in subsequent seasons has a greater potential to improve soil carbon content than continuous conventional tillage practice.

On the other hand, crop rotation significantly influenced soil organic carbon content. The results showed M – M and C – M to record higher SOC values at the 0 – 15 and 15 – 30 cm depths than C – C. The higher amount of root residue addition by M – M as well as the complementary effect of high quantity and quality residue under C – M may account for the higher SOC observed. It is also likely that the increased residue under M – M and C – M enhanced soil faunal population and contributed to SOC additions. On the other hand, residue added by C – C was usually small with high decomposition and mineralization rate, thus resulting in a lower SOC. By implication, plant and animal residues are the main source of SOC, therefore, higher SOC is expected under systems that add higher amount of residue, more so, when high quality and quantity residue sources are alternated in a given system.

Similarly, mulching significantly increased SOC at both soil depths than no-mulch. Obviously, the higher residue amount as indicated under crop rotation, could also account for the SOC differences under mulching. In addition, mulch has a higher tendency to reduce the effect of insolation and erosion on the soil surface, and conserve SOC. Meanwhile, under no-mulch, rapid carbon mineralization and loss may have contributed to the lower SOC concentration recorded. Ghimire *et al*. (2011) reported that SOC was increased at the 0 – 50 cm soil depth under mulch than no-mulch.

The impact of factor interactions, tillage x crop rotation x mulching, on SOC was significant under both soil depths. The trend of the results suggest that the impact of the treatment interaction depended on the magnitude of the factors involved in the interaction.

Subsequently, the interactions, CT – NT/C – M/+R, CT – NT/M – M/+R and CT – NT/C – C/+R were complementary in enhancing SOC. These, therefore recorded higher SOC than the main effect of each factor acting sole and sufficiently emphasized the importance of CT – NT and mulching to increasing SOC.

4.11.0 The impact of tillage, crop rotation, mulching and their interactions on particulate organic carbon

4.11.1 Results

The results of tillage, crop rotation, mulching and their interactions on particulate organic carbon are presented in Table 4.11. Similar to soil organic carbon, particulate organic carbon (POC) decreased as depth increased and in most cases, the differences between depths under the main treatment effects was significant. Tillage practice, CT – NT gave significantly higher POC in the 0 – 15 cm and 15 – 30 cm depths than CT – CT.

The impact of crop rotation on POC also varied significantly among the systems compared with C – M and M – M recording higher values than C – C at the 0 – 15 and 15 – 30 cm depths. However, no significant ($P < 0.05$) difference was observed between C – M and

M – M at both soil depths. The trend of crop rotation effect on POC was C – M > M – M **Table 4.11. Effect of tillage, crop rotation and mulching on particulate organic carbon**

	*Particulate organic carbon (g kg^{-1} soil)			
	Soil depth (cm)			
Practice	**0 - 15**	**15 - 30**		
Tillage			**CV (%)**	**LSD$_{0.05}$**
CT – CT	2.75	1.86	29.7	0.46
CT – NT	4.67	3.02	42.4	1.10
CV (%)	39.6	36.4		
LSD$_{0.05}$	1.24	1.02		
Crop rotation				
C – C	3.23	1.84	31.2	0.67
M – M	3.79	2.88	41.3	ns
C – M	4.10	2.61	61.4	ns
CV (%)	47.8	40.5		
LSD$_{0.05}$	0.52	0.48		

Mulching				
-R	3.01	1.96	43.2	0.72
+R	4.40	2.93	44.0	1.09
CV (%)	43.9	43.4		
$LSD_{0.05}$	0.68	0.59		
Interactions				
CT – CT/C – C/-R	2.96	1.54	17.3	1.36
CT– CT/ C-C/+R	3.23	2.03	9.2	0.84
CT– CT/M–M/-R	2.37	1.46	25.0	ns
CT– CT/M–M/+R	3.13	2.38	5.6	0.54
CT– CT/C–M/-R	1.83	1.45	14.1	ns
CT– CT/C–M/+R	2.96	2.32	15.3	ns
CT – NT/C – C/-R	2.50	1.43	27.0	ns
CT–NT/ C – C/+R	4.23	2.36	28.5	ns
CT–NT/M–M/-R	4.73	3.43	17.2	ns
CT–NT/M–M/+R	4.93	4.24	4.0	0.65
CT–NT/C–M/-R	3.68	2.42	11.9	ns
CT–NT/C–M/+R	7.94	4.27	18.0	ns
Mean	3.71	2.44		
CV (%)	25.3	33.5		
$LSD_{0.05}$	1.40	1.21		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference, *%value = table value x 0.1

> C – C and M – M > C – M > C – C in the former and latter depths respectively. Also, though significant differences in POC was observable under C – C, the impact of C – M and M – M did not differ between depths.

Mulching, on the other hand, produced significantly higher POC than no-mulch at both 0 – 15 cm and 15 – 30 cm depths. Similarly, inter depth differences was significant under the two mulching practices.

The tillage x crop rotation x mulching interaction also showed significant intra depth effect and in a few cases, inter depth. The results showed significantly higher POC values under

CT – NT/M – M/+R, CT – NT/M – M/-R and CT – NT/C – M/+R at both 0 – 15 cm and 15 – 30 cm depths.

4.11.2 Discussion

POC is considered as a very sensitive indicator of SOC change. Its amount in soil at a point in time is a factor of SOC content and the proportion of freshly added organics from residues and rhizodepositions, mineralization and the impact of soil management practices. In this study, tillage, crop rotation and mulching effected changes in the concentration of POC at the 0 – 15 and 15 – 30 cm soil depths and the results are thus discussed.

Particulate organic carbon was significantly higher under CT – NT at all depths, following a similar trend as observed under SOC. This was not surprising because of significant positive correlation between POC and SOC. Thus, an increase in SOC increases the amount of POC. It is therefore possible that the same factors such as lower frequency of soil disturbance, higher amount of organic material returned, and lesser aerobic than anaerobic soil microbes, which underscored the increases in SOC increased POC concentration in the soil. On the other hand, under CT – CT, higher decomposition and oxidation of SOC may reduce POC especially where the return of organic matter is slower than the rate it is oxidized. de Figueiredo *et al*. (2010) and Wang and Sainju (2014) reported that systems that reduced carbon mineralization, increased carbon recovery. The implication is that, practices that retain higher POC would tend to increase soil structural stability as observed under CT – NT and enhance soil fertility, thus, creating favourable soil condition for sustained crop production.

In addition to these impacts, crop rotation practices differed significantly in their influence on POC. The results showed higher POC under C – M and M – M than C - C in the 0 – 15 and 15 – 30 cm depths respectively. Differences in root biomass, rhizodepositions, fungal hyphae and arbuscular mycorrhiza associated with plant roots may account for the variations observed. The complementary influence of high root biomass and low C:N ratio of C – M rotation might have enhanced carbon decomposition of freshly added organic matter and thus, increased POC concentration in the 0 – 15 cm depth. At the 15 – 30 cm depth, higher POC under M – M may be attributed to slower decomposition despite the higher residue added by maize roots. In similar studies, Salvo *et al*. (2010) reported higher POC under legume-cereal rotation contrary to Sainju (2012) who indicated that cereal monoculture increased POC than in rotation with legume. On the other hand, the generally lower POC under C – C can be explained by the easily decomposable, mineralizable and lower mass of cowpea residue returned.

The impact of mulching on POC was consistent and significantly higher under mulch than no-mulch in the 0 – 15 and 15 – 30 cm depths. The results of the study suggest that although mulch is retained on the soil surface, its impact on SOC and POC transcends the immediate top soil layer. Thus by enhancing soil moisture storage, reducing insolation, soil surface temperature, surface runoff and erosion, promoting beneficial fauna activity and increasing the amount of organic matter, POC is increased under mulch than nomulch. It is also important to indicate that photodecomposition of crop residue mulch could also increase the fraction of POC in the top 0 – 15 cm depth. The intensity of insolation transforms the colour of added organic residues and finally disintegrates these into smaller fragments adding to the POC. On the other hand, the direct impact of insolation under on no-mulch may decrease POC through increased soil temperature and accelerated microbial decomposition depending on availability of soil moisture. Also, the generally low soil moisture under no-mulch might have reduced the productivity of the system and thus returned lower mass of above-and-belowground biomass, SOC and POC. Therefore, mulching is essential in enhancing and sustaining POC in the soil.

The results further showed that, the tillage x crop rotation x mulching interaction significantly influenced particulate organic carbon (Table 4.11). The implication is that a combination of favourable cropping practices would enhance particulate organic carbon than the effect of the sole treatments. These could promote soil fertility management and increase crop yield. The overall impact of the interactions thus showed a complementary effect under CT – NT/C – M/+R, CT – NT/M – M/+R and CT – NT/M – M/-R in enhancing POC. The magnitude of the complementary effect however depends on the type and level of the interacting factors.

4.12.0 The impact of tillage, crop rotation, mulching and their interactions on water extractable carbon

4.12.1 Results

The results of water extractable carbon (WEC), used as a measure of soluble carbon as impacted by tillage, crop rotation, mulching and their interactions have been presented in Table 4.12. Water extractable carbon generally decreased with soil depth under all practices assessed by the study, however, differences in the values between depths were not always significant. Among the tillage practices, intra-depth differences were significant at both depths with CT – NT recording higher values than CT – CT. Inter-depth differences were however significant under CT – CT but not CT – NT.

The impact of crop rotation on WEC differed significantly at both 0 – 15 and 15 – 30 cm depths. In the former case, M – M recorded higher values than C – M but the two were not statistically different, however, these were significantly higher than C – C and were ranked as M – M > C – M > C – C. In the latter depth, crop rotation impact followed the trend, C – M > M – M > C – C with C – M recording significantly higher values than the other factors which did not differ statistically. On the other hand, differences between depths were significant under M – M but not C – M and C – C.

Mulching generally recorded higher WEC than no-mulch at both depths with differences being significant at the 0 – 15 and 15 – 30 cm depths. Similarly, variability between depths under mulching and no-mulch was also significantly different.

The tillage x crop rotation x mulching interaction significantly influenced WEC at both depths with higher values often recorded under interactions which included tillage rotation and mulching.

Table 4.12. Effect off tillage, crop rotation and mulching on water extractable organic carbon

	*Water extractable carbon (mg kg^{-1} soil)			
	Soil depth (cm)			
Practice	**0 - 15**	**15 - 30**		
Tillage			**CV (%)**	**LSD$_{0.05}$**
CT – CT	11.74	8.67	20.8	1.44
CT – NT	16.17	12.79	35.0	ns
CV (%)	31.7	21.9		
LSD$_{0.05}$	3.19	3.28		
Crop rotation				
C – C	12.49	9.60	32.8	ns
M – M	14.84	10.66	29.9	3.25
C – M	14.53	11.93	44.3	ns
CV (%)	35.5	28.6		
LSD$_{0.05}$	1.84	1.12		

Mulching				
-R	11.17	8.55	21.7	1.45
+R	16.74	12.91	31.8	3.20
CV (%)	28.9	29.3		
$LSD_{0.05}$	1.37	1.11		
Interactions				
CT – CT/C – C/-R	10.87	6.96	10.9	3.40
CT– CT/ C-C/+R	12.05	10.67	10.4	ns
CT– CT/M–M/-R	12.15	7.73	23.7	ns
CT– CT/M–M/+R	12.23	9.16	23.2	ns
CT– CT/C–M/-R	10.28	6.10	17.3	ns
CT– CT/C–M/+R	12.87	11.38	7.6	ns
CT – NT/C – C/-R	8.93	7.93	0.4	ns
CT–NT/ C – C/+R	18.10	12.87	18.9	ns
CT–NT/M–M/-R	13.87	11.87	4.7	ns
CT–NT/M–M/+R	21.12	13.86	7.5	4.57
CT–NT/C–M/-R	10.92	10.69	1.6	ns
CT–NT/C–M/+R	24.05	19.54	9.0	ns
Mean	13.95	10.73		
CV (%)	13.6	14.4		
$LSD_{0.05}$	3.38	2.82		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference, *%value = table value x 0.0001.

Mulching generally recorded higher WEC than no-mulch at both depths with differences being significant at the 0 – 15 and 15 – 30 cm depths. Similarly, variability between depths under mulching and no-mulch was also significantly different.

The tillage x crop rotation x mulching interaction significantly influenced WEC at both depths with higher values often recorded under interactions which included tillage rotation and mulching.

4.12.2 Discussion

Water extractable carbon is a fraction of soil organic carbon obtainable by shaking soil with deionized water as extractant. It is labile, varies in space and time, soluble in water, leachable hence could contaminate ground water and cause environmental pollution. In the soil, water extractable carbon is bonded to cations including Al^{3+}, Fe^{3+}, and NH_4^+ on colloidal surfaces at low pH. It is however the most readily available energy source for microbial activity, growth and multiplication. Soil microbes facilitate nutrient uptake, control soil pathogens, soil aggregation and decompose organic resources. Therefore, production systems that enhance carbon input from root biomass, root exudates and aboveground biomass as well as moisture storage and reducing leaching, may increase water extractable carbon, soil aggregate stability and fertility.

The influence of tillage on WEC appear to follow a similar pattern as observed for SOC and POC in previous discussions. This suggests that the variables that explained the differences in the impact of tillage on the former soil parameters, may equally account for the variability in WEC. This is evidenced by the positive and significant correlation of SOC, POC and WEC. Residue amount, decomposition, and degree and frequency of soil disturbance could offer explanation to the differences in the impact of tillage on WEC. In this study, CT – NT significantly increased WEC at both depths than CT – CT, with the 0 – 15 cm recording higher values than the 15 – 30 cm depth. This indicates that much of the plant resources were concentrated at the 0 – 15 cm depth hence it is likely that microbial activity was higher at this depth. Wang and Wang (2011) reported that microbial biomass showed a strong positive correlation to water extractable carbon and also, that plant residues are a major source of water extractable carbon. Therefore, the higher WEC under CT – NT may be attributable to its one-time plough-harrow practice with its associated benefits of retaining the aboveground and belowground biomass and reduced carbon oxidation. On the other hand, increased aerobic activity and carbon evolution due to increased residue-soil contact, low or no residue on soil surface, tendency for high erosion and surface runoff under CT – CT could account for the lower WEC. Wu *et al*.

(2010) reported that ploughing decreased WEC because of increased mineralization and Hamkalo and Bedernichek (2014) also indicated that residue removal and leaching decreased WEC. The implication is that continuous conventional tillage would make carbon susceptible to microbial attack, pulverize soil aggregates, decrease carbon input, and WEC than conventional tillage followed subsequently by no-tillage.

Aside tillage, the water extractable carbon of the soil was impacted upon by crop rotation. The cowpea-maize rotation (C – M) and continuous maize monoculture (M – M) tended to increase water extractable carbon than continuous cowpea monoculture (C – C) signifying the importance of crop type and rotation in soil carbon management. The liabile nature of WEC suggests that this carbon pool is derived from freshly added or partially decomposed plant and animal matter. In this study, crop rotation impact on WEC can be alluded to the quality and quantity of root biomass and rhizodepositions, and their decomposability. Poor quality root biomass has high C:N ratio, decay slowly and is characterized by high phenol and lignin concentration (Agbede *et al*., 2013). These properties stimulate microbial diversity, increase the binding to aggregates and favour the storability of carbon in the soil. On the other hand, being a major source of WEC, higher amount of root biomass and secretions are important for its replenishment as indicated by Jia *et al*. (2006) and de Figueiredo *et al*. (2010). Thus the combined poor quality and high quantity biomass under M – M and the complementary impact of higher quality and high amount of biomass under

C – M as also explained for SOC and POC might have contributed to the higher WEC noticed. Contrariwise, rapid decomposition of high quality and low root biomass under C – C could explain the lower WEC recorded. In effect, cowpea-maize rotation and continuous maize monoculture can increase soil fertility and productivity over time through increased soil carbon content, microbial diversity and soil aggregation.

Mulching, on the other hand, cushions the soil surface against the impact of raindrop, reduce surface runoff, erosion, and nutrient loss. It reduces the impact of insolation, evaporation and regulates soil temperature while increasing moisture storage through improved soil aggregation. The higher tendency of mulch to improve soil condition, population and activity of soil fauna, in addition to residue supply, may account for higher water extractable carbon. Wang and Sainju (2014) indicated that surface application of mulch reduced soil carbon loss. As observed in this study, mulch enhanced soil physical and hydro-physical condition, and SOC. Crop residue mulch is a major source of water extractable carbon hence the removal of residue is likely to decrease the supply of WEC as was observed under no-mulch. The results of this study suggest that despite the many competing uses of mulch, it is very much needed to increase and maintain soil carbon fractions and water extractable carbon.

The tillage x crop rotation x mulching interactions differed significantly in their impact on water extractable carbon. On the basis of the magnitude of each factor in the interaction, the following complementary treatments were identified, CT – NT/C – M/+R, CT – NT/ M – M/+R and CT – NT/C – C/+R. These treatment interactions recorded higher values of WEC than their main effects. In this study, CT – NT and +R appear to sustain WEC in systems that rapidly decompose organic matter as under C – C through improved soil condition and reduced nutrient loss. Tillage rotation combined with mulching and cropping systems has a higher potential to enhance soil water extractable carbon content.

4.13.0 The impact of tillage, crop rotation, mulching and their interactions on mineralized carbon

4.13.1 Results

The influence of tillage, crop rotation, mulching and their interactions on mineralized carbon, are presented in Table 4.13.

Similar to SOC, POC and WEC, mineralized carbon decreased with soil depth with higher values recorded at the 0 – 15 cm than the 15 – 30 cm depth. The impact of tillage showed higher values of mineralized carbon under CT – CT than CT – NT at both 0 – 15 and 15 – 30 cm depths with significant differences observed at the former but not the latter depth. Inter-depth differences was also significant under all the tillage practices.

Crop rotation practices showed significant variation in mineralized carbon at the intra-and inter-depth levels. At the intra-depth level, mineralized carbon increased in the

Table 4.13. Effect of tillage, crop rotation and crop residue mulch on mineralized carbon

	*Mineralized carbon (mg CO_2 g^{-1})			
	Soil depth (cm)			
Practice	**0 - 15**	**15 - 30**		
Tillage			**CV (%)**	**$LSD_{0.05}$**
CT – CT	0.97	0.57	17.1	0.09
CT – NT	0.74	0.51	25.5	0.10
CV (%)	15.5	29.4		

$LSD_{0.05}$				0.07		ns		
Crop rotation								
C – C		0.95	0.49	30.6	0.18			
M – M		0.75	0.56	14.6	0.08			
C – M		0.86	0.58	20.0	0.12			
CV (%)				18.6		29.4		
$LSD_{0.05}$				0.06		0.02		
Mulching								
-R	0.83	0.44	26.0	0.11				
+R	0.88	0.65	17.6	0.09				
CV (%)				20.6		22.1		
$LSD_{0.05}$				0.03		0.01		
Interactions								
CT – CT/C – C/-R				1.15		0.54	13.4	0.39
CT– CT/ C-C/+R				1.08		0.66	3.8	0.11
CT– CT/M–M/-R				0.78		0.54	4.4	0.10
CT– CT/M–M/+R				0.85		0.54	1.0	0.02
CT– CT/C–M/-R				0.82		0.54	1.8	0.04
CT– CT/C–M/+R				1.13		0.64	5.4	0.16
CT – NT/C – C/-R				0.84		0.12	9.1	0.15
CT–NT/ C – C/+R				0.72		0.64	2.8	0.06
CT–NT/M–M/-R				0.65		0.44	6.7	0.13
CT–NT/M–M/+R				0.74		0.72	1.1	ns
CT–NT/C–M/-R				0.76		0.45	5.0	0.10
CT–NT/C–M/+R				0.74		0.70	3.3	ns
Mean				0.85		0.54		
CV (%)				6.1		4.5		
$LSD_{0.05}$				0.09		0.06		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference, *% value = table value x 0.1.

order M – M < C – M < C – C at the 0 – 15 cm depth and C – M > M – M > C – C at the 15 – 30 cm depth. In the former case, mineralizable carbon differed significantly among all the cropping systems compared, however in the latter case, significantly lower values were recorded under C – C than M – M and C – M which were not statistically different.

The impact of mulching on mineralized carbon followed a similar trend as SOC, POC and WEC with mulch recording higher values than no-mulch. In this study, mineralized carbon was significantly higher under mulch than no-mulch at both soil depths.

Treatment interactions, tillage x crop rotation x mulching significantly influenced mineralized carbon at both the 0 – 15 and 15 – 30 cm depths. Generally, treatment interactions with CT – CT increased mineralized carbon in the 0 – 15 cm depth compared to the 15 – 30 cm depth where practices that included mulch recorded higher values.

Subsequently, complementary treatment interactions were recorded under CT – CT/C –

C/-R, CT – CT/C – C/+R and CT – CT/C – M/+R in the 0 – 15 cm depth and CT – CT/C – C/+R, CT – NT/M – M/+R and CT – NT/C – M/+R at the 15 – 30 cm depth.

4.13.2 Discussion

Carbon mineralization can decrease carbon stock while increasing its atmospheric concentration. Crop production practices have diverse impacts on carbon mineralization, because they determine the soil condition, amount of organic resources and diversity of microbes. These production practices are therefore important for soil carbon management. The results of this study suggests that tillage, crop rotation and mulching effected changes in soil condition which affected microbial activity and diversity resulting in variability in soil carbon mineralized.

Continuous conventional tillage generally recorded higher values of mineralized carbon than the conventional-no-tillage practice with significant differences observed at the top 0 – 15 cm but not 15 – 30 cm depth. Also, significant differences were noticed between depths under each of the tillage practices with higher values recorded at the former than the latter depth. Higher mineralized carbon at the 0 – 15 cm is an indication of increased microbial activity and higher fraction of organic matter than the 15 – 30 cm depth. The mineralized carbon correlated positively with SOC. Enhanced SOC therefore presents a greater substrate for microbial decomposition with a resultant increase in mineralized carbon as similarly reported by Tan *et al*. (2007). However, when soil aeration becomes restricted due to increased microporosity, microbial activity could be decreased to slow down the mineralization of carbon despite the presence of high SOC, as observed by Dou *et al*. (2008) and Mangalassery *et al*. (2014). This may explain the lower mineralized carbon under CT – NT than CT – CT. On the other hand, the favourable conditions presented by CT – CT for carbon mineralization may account for its higher mineralized carbon. Continuous conventional tillage is therefore not suitable for carbon sequestration due to possible losses through CO_2 evolution, leaching and erosion. This can adversely affect soil physical and hydro-physical properties, its fertility and productivity as well as increase the atmospheric concentration of CO_2 resulting in greenhouse effect.

Crop type and crop rotation differed significantly in their impact on mineralized carbon.

The results showed C – C and C – M to record higher mineralized carbon at the top 0 – 15 cm depth and C – M and M – M at the 15 – 30 cm depth (Table 4.13). The trend of cropping system influence on mineralized carbon suggests that root biomass quality as well as quantity were important determinants. At the 0 – 15 cm depth, high biomass quality of cowpea with its complementary effect on maize might have accounted for the higher carbon mineralized under C – C and C – M than M – M. Even though the quality of root biomass was not measured in this study, the aboveground biomass quality (C:N ratio) at harvest was 33.15 for maize residue and 28.05 for cowpea (Table 4.3c). Observation from the field however showed that at harvest, cowpea root biomass had almost completely decomposed unlike maize whose roots appeared fresh and bulky. It is thus likely that higher root biomass quality of cowpea enhanced the activity of decomposers resulting in increased mineralization. Similar accounts were given by Salvo *et al*. (2010) who reported that soybean biomass decomposed twice and a half times faster than maize residue and Adiku *et al*. (2008) who observed higher carbon mineralization under maize-legume rotation than maize monoculture. The implication is that, though quick nutrient release from rapid mineralization is an advantage, the process may deplete soil carbon through leaching, erosion, gaseous evolution and soil degradation if carbon replenishment does not match mineralization.

Mineralized carbon was significantly higher under mulching at all depths. The mulch presumably increased substrate availability, soil moisture, and regulated soil temperature which might have stimulated microbial activity and increased soil respiration. The results also agree with the positive effect of mulch on soil compaction, aggregate stability and SOC observed in this study. Wright *et al*. (2007) and Cheng-Fang *et al*. (2012) reported greater mineralized carbon under mulch. On the other hand, lower SOC or substrate availability, microbial population and function, and moisture content despite the tendency for higher temperature under –R may account for the decreased mineralized carbon.

The results further showed significant effect of tillage x crop rotation x mulching on mineralized carbon. Significantly higher values recorded under treatment interactions were CT – CT/C – C/-R, CT – CT/C – C/+R and CT – CT/C – M/+R at the 0 – 15 cm depth and CT – CT/C – C/+R, CT – NT/M – M/+R and CT – NT/C – M/+R at the 15 – 30 cm, indicating greater impact of continuous conventional tillage at the former than the latter depth. These interactions also showed complementary treatment effects, in that, values recorded under each of these interactions were higher than that of the individual factors acting sole.

4.14.0 The impact of tillage, crop rotation, mulching and their interactions on the grain and stover yield of maize

4.14.1 Results

The results of maize grain and stover yield as affected by tillage, crop rotation, mulching and their interactions are presented in Table 4.14. The trend of the results showed a decrease in stover yield as grain yield increased. Tillage impact on maize grain yield was significant in 2014 but not 2013, with CT – NT recording higher values than CT – CT in both years. On the other hand, yield differences by year was significant under the former and latter tillage practices.

The impact of crop rotation on maize grain yield was not significant in both years of study, however, C – M recorded higher values than M – M throughout the period. Meanwhile, significant differences was observed between 2013 and 2014 under both C – M and M – M

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Table 4.14. Effect of tillage, crop rotation and mulching on maize grain and stover yields

		Grain (Mg ha^{-1})			Stover (Mg ha^{-1})				
Practice	**2013**	**2014**	**CV (%)**		**LSD$_{0.05}$**	**2013**	**2014**	**CV (%)**	
Tillage									
CT – CT	2.58	3.74	12.1	0.34	6.76	6.33	20.5		
CT – NT	3.30	4.01	13.8	0.45	6.95	5.99	17.5		
CV (%)	32.5	14.4			30.2	22.8			
LSD$_{0.05}$		ns	0.15				ns	ns	
Crop rotation									
M – M	2.59	3.72	17.7	0.50	6.88	6.31	21.3		
C – M	3.29	4.02	8.6	0.28	6.83	6.02	16.7		
CV (%)		32.7	14.2				30.2	22.9	
LSD$_{0.05}$		ns	ns				ns	ns	
Mulching									
-R 2.35	3.47	16.8	0.44	5.46	5.13	22.3			
+R 3.53	4.28	10.9	0.38	8.25	7.19	16.4			
CV (%)		27.4	9.4				20.4	14.8	
LSD$_{0.05}$		0.37	0.32				1.19	0.38	
Interactions									
CT– CT/M–M/-R		1.83	3.32	19.4	ns		4.98	5.59	26.7
CT– CT/M–M/+R		2.61	3.90	10.2	1.16		8.72	6.63	20.6
CT– CT/C–M/-R		2.37	3.42	17.0	ns		5.56	4.42	10.3
CT– CT/C–M/+R		3.50	4.31	2.1	0.28		7.78	6.65	10.0
CT–NT/M–M/-R		2.02	3.46	19.6	ns		5.54	6.26	12.0
CT–NT/M–M/+R		3.89	4.21	15.5	ns		8.28	7.39	14.1
CT–NT/C–M/-R		3.16	3.66	7.3	ns		5.78	4.23	27.2
CT–NT/C–M/+R		4.13	4.69	6.8	ns		8.21	8.08	10.3
Mean		2.94	3.87				6.86	6.16	
CV (%)		13.5	8.9				14.7	5.1	
LSD$_{0.05}$		1.45	0.55				ns	0.96	

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Mulching and treatment interactions also showed significant impact on maize grain yield. Mulching generally recorded higher maize grain yield than no-mulch with the two treatments being significantly different within and between the years of study. The tillage x crop rotation x mulching interaction significantly influenced maize grain yield in both years of study with higher values often recorded under interactions which included mulching.

Stover yield did not vary significantly under tillage and crop rotation practices within and between the years of experimentation. Tillage impact on stover yield was not consistent as higher values were recorded under CT – NT and CT – CT in 2013 and 2014, respectively. On the other hand, the influence of crop rotation showed a higher stover yield under M – M than C – M in 2013 and 2014.

Mulch recorded significantly higher stover yield than no-mulch in 2013 and 2014, however, no significant differences were observed under the former and latter practices between the years of study.

The impact of tillage x crop rotation x mulching interactions on stover yield was significant in 2014 but not in 2013. Similar to the observation made under grain yield, treatment interactions including mulch recorded higher stover yields than with no-mulch.

4.14.2 Discussion

The results of this study showed that tillage, crop rotation, mulching and their interactions influenced maize grain and in a few cases, the stover yield (Table 4.14). Tillage effect on maize grain yield was significantly higher under CT – NT than CT – CT in 2014 while in 2013, no statistical differences were observed. The results suggest the higher yield under CT – NT may be due to its higher soil physical and hydro-physical as well as chemical conditions than CT – CT. The greater impact of CT – NT on maize grain yield with time can therefore be attributed to the cumulative influence of the three successive no-tillage after the first conventional tillage leading to enhancement in soil structure, lowering of soil compaction which might have favoured rooting and water relations. A study of the soil's physical and hydro-physical effect on grain yield showed that cumulative moisture storage, cumulative infiltration amount, bulk density, total porosity, wet aggregate stability and saturated hydraulic conductivity explained 69.9 % variation in maize grain yield in 2014 (Appendix 19). Apart from bulk density and saturated hydraulic conductivity which negatively correlated grain yield, the remaining soil variables showed positive correlation indicating that an increase in these parameters would improve soil condition with benefits of increasing soil productivity. This was similarly noticed for soil organic carbon and the carbon fractions which all showed positive relation with maize grain yield with SOC explaining 51.2 % and WEC, 43.9 % while POC and mineralized C accounted for < 30 % variation. However, the regression of SOC and mineralized carbon together with the selected physical and hydro-physical properties, accounted for 74.4 % of the variation in grain yield (Appendix 19). This implies that tillage practice that enhanced these properties could also create the right soil condition for increased grain yield. The implication is that, a one-time conventional tillage followed subsequently by no-tillage tends to minimize soil disturbance while retaining previous crop residues, the cumulative effect of which improve the physical, chemical and biological status of the soil with a positive impact on maize grain yield.

Crop rotation on the other hand, did not differ in their impact on maize grain yield in both years, however, the impact of the practices was greater and significant with time with C –

M consistently recording higher values than M – M. In the former situation, the similarity of the impact of these cropping systems on maize grain influencing factors could account for the similar yield observed. The significant differences with time may therefore be due to the more favourable moisture relations under C – M than M – M.

Maize grain and stover yield were significantly higher under mulch than no-mulch in both years of the study. The mulch as observed under most of the soil components measured showed a greater impact in improving soil condition. This was manifested through increased moisture and cumulative moisture stored, lower soil compaction, higher total porosity and SOC all of which explained 74.4 % of the variation in maize grain yield. Improvement in these soil variables might have culminated in good soil condition which enhanced plant growth and yield.

Similar to the main effects discussed above, the results showed that tillage x crop rotation x mulching significantly influenced maize grain yield and stover yield in 2014. The implication is that the magnitude of the impact of the interaction factors depend on each other. Thus, whereas the differences in the main effect of a factor, such as crop rotation on maize grain and stover yield may not be significant in 2013 and 2014, it may be significant as the factor interacts with others.

4.15.0 The impact of tillage, crop rotation, mulching and their interactions on cowpea grain and haulm yield

4.15.1 Results

The results of tillage, crop rotation, mulching and their interactions on cowpea grain and haulm yield are presented in Table 4.15. Cowpea grain and stover yield was generally lower in 2014 than in 2013. Tillage impact on cowpea grain yield was significantly different in 2014 but not 2013 with CT – NT recording higher values in the former year.
The differences in grain yield between 2013 and 2014 was significant under CT – CT but not CT – NT.

With respect to crop rotation, significantly higher grain yield was recorded under C – M than C – C in 2014. Though higher value was recorded under the former in 2013, the difference was not significant from the latter. Also, differences in crop rotation impact between the two years was significant under C – C but not C – M.

Higher grain yield was recorded under mulch in 2013 than in 2014. No-mulch produced significantly ($P < 0.05$) higher cowpea grain yield in 2014. The results also showed significant differences in the impact of mulch but not no-mulch between 2013 and 2014.

Treatment interactions, tillage x crop rotation x mulching significantly influenced cowpea grain yield with higher values recorded mostly under interactions which included CT – NT and mulch in 2013, and CT – NT in 2014.

The overall pattern was however inconsistent. Cowpea grain yield was thus significantly higher under CT – CT/ C – C/+R, CT – CT/C – M/+R and CT – NT/C – C/-R in 2013 and CT – NT/C – C/-R, CT – NT/C – M/-R and CT – NT/C – M/+R in 2014.

Cowpea haulm yield was significantly higher under CT – CT in 2013 but statistically undistinguishable from CT – NT in 2014 despite the higher values recorded under the former treatment. Comparison of tillage impact between 2013 and 2014 showed significant effect under CT – CT only.

On the other hand, crop rotation impact on haulm yield differed significantly with C – C recording higher values in 2013, and C – M in 2014. The results also showed significant differences in haulm yield under C – C between the former and latter year of cropping.

Table 4.15. Effects of tillage, crop rotation and mulching on cowpea grain and haulm yields

	Grain (Mg ha^{-1})				Haulm (Mg ha^{-1})			
Practice	**2013**	**2014**	**CV (%)**	**LSD$_{0.05}$**	**2013**	**2014**	**CV (%)**	**LSD$_{0.05}$**
Tillage								
CT – CT	2.12	1.24	44.5	0.67	3.49	1.92	52.4	1.28
CT – NT	1.74	1.51	40.5	ns	2.69	1.78	52.5	ns
CV (%)	52.4	38.2			44.0	52.4		
LSD$_{0.05}$	ns	0.22			0.33	ns		
Crop rotation								
C – C	2.05	1.10	41.4	0.58	3.93	1.19	27.4	0.63
CV (%)	53.1	33.2			35.5	34.8		
C – M	1.81	1.65	41.4	ns	2.25	2.52	32.1	ns
LSD$_{0.05}$	ns	0.38			0.24	0.40		
Mulching								
-R	1.92	1.16	35.7	ns	3.20	2.28	45.9	ns
CV (%)	53.5	33.5			46.1	46.3		
+R	1.95	1.11	51.5	0.70	2.98	1.43	62.0	1.22
LSD$_{0.05}$	ns	0.39			0.32	0.10		
Interactions								
CT– CT/C – C/-R	1.55	1.35	7.1	ns	4.37	2.30	12.4	1.45
CT– CT/C – C/+R	2.62	0.74	19.9	1.18	4.55	0.43	6.3	0.55
CT– CT/C–M/-R	1.12	1.48	22.1	ns	1.32	2.54	12.3	0.83
CT– CT/C–M/+R	3.18	1.39	4.9	0.39	3.72	2.41	6.8	0.73
CT–NT/C – C/-R	3.32	1.70	14.9	1.31	4.51	1.55	8.7	0.93
CT–NT/C – C/+R	0.17	0.61	54.0	ns	2.27	0.45	6.6	0.31

CT–NT/C–M/-R	1.66	2.03	6.5	ns	2.61	2.69	8.7	ns
CT–NT/C–M/+R	1.26	1.69	12.8	ns	1.36	2.43	5.4	0.35
Mean	1.93	1.37			3.09	1.85		
CV (%)	11.9	21.2			11.2	6.2		
$LSD_{0.05}$	0.49	0.46			0.50	0.40		

CT – CT: continuous conventional tillage, CT – NT: tillage rotation, C – C: cowpea monoculture, M – M: maize monoculture, C – M: cowpea-maize rotation, -R: no residue mulch, +R: residue mulch retained, ns: not significant at F probability 0.05, CV: coefficient of variation and LSD: least significant difference.

Mulch generally recorded lower haulm yield than no-mulch with the differences being significant in both years. Meanwhile, comparison of the two years showed significant differences in haulm yield under mulch and not no-mulch.

The treatment interactions showed significant effect of tillage x crop rotation x mulching on cowpea haulm yield. Significantly higher values were recorded under CT – CT/C – C/R, CT – CT/C – C/+R and CT – CT/C – M/+R in 2013 and CT – CT/C – M/-R, CT – CT/C – M/+R, CT – NT/C – M/-R and CT – NT/C – M/+R in 2014.

4.15.2 Discussion

Cowpea is a very important multipurpose crop. Its grains are used as food serving as the major source of dietary protein. The crop, by covering the soil surface with its dense canopy later in its growth, minimizes the direct impact of raindrop and insolation, and enhances soil fertility due to its biological nitrogen fixing potential and easily decomposable high quality residue. It therefore reduces the mining of soil N and increases SOC content making it a favourable crop for sustainable soil management. For these and other benefits including decreased pests and disease incidence, soil moisture availability and storage, and control of soil compaction, which could be derived by and/or achieved together with a succeeding crop, it is encouraged that the cowpea is cultivated in rotation with non-leguminous crop such as maize. It is therefore likely that crop production practices that increase the productivity of cowpea could also enhance its rotational benefits. The results of this study showed that cowpea grain and haulm production was affected by tillage, crop rotation, mulching and their interactions.

Cowpea grain yield was significantly higher under CT – NT in 2014 but not in 2013 (Table 4.15). The reasons for the inconsistency in the values recorded is not immediately clear, however, it is likely that, the variation in soil physical and chemical properties may account for the significant differences in 2014. A match of a cause-effect relationship between yield and cumulative moisture content, bulk density, total porosity, saturated hydraulic conductivity, penetration resistance and cumulative infiltration amount showed that these properties significantly explained the variation in maize grain yield and more so in combination with SOC and mineralized carbon. A further analysis using the correlation matrix in principal component analysis identified bulk density, cumulative moisture content, and carbon mineralization as the key soil properties affecting cowpea grain yield (Appendix 25). The results indicated that, PC2 accounted for 62.2 % and PC3, 78.6 % of the variation in grain yield mainly contributed by carbon mineralization and bulk density respectively, and also showed negative correlation with yield at the corresponding values of 62.0 % and 71.2 %. The implication of this observation is that, grain yield would increase as rapid carbon mineralization and compaction are reduced. Thus, practices that reduce carbon loss, moisture stress and enhance root growth has the potential to enhance cowpea growth and yield as similarly reported by Mandal *et al*. (2003) and Peprah (2014), but excess moisture may dampen growth and decrease the yield of cowpea (Mupangwa *et al*., 2012; Faloye and Alatise, 2015). It therefore appears that the mechanical loosening of soil under CT – CT might have facilitated quick establishment, growth and yield aided by the higher moisture usually stored in the top 0 –

15 cm layer of the soil. However, due to rapid carbon mineralization which could decrease SOC and the tendency for increased compaction as well as the inferred higher unproductive moisture loss, CT – CT may become restrictive to root growth and decrease yield. In the case of haulm yield, the results also showed positive and highly significant correlation between grain and haulm yield, which could imply that, the factors which affected the former may equally explain the pattern of haulm yield observed. The impact of tillage on haulm yield was significantly different in 2013 but not in 2014 with consistently higher values recorded under CT – CT. In the case of 2014, the results appear to depart from the strong positive grain-haulm correlation suggesting that high biomass did not necessarily translate into high grain yield. Thus, the likelihood of reduced vegetative biomass may account for the generally lower haulm yield under CT – NT.

Similar to the impact of tillage, crop rotation effect on cowpea grain yield was significantly different in 2014 with higher value recorded under C – M but not in 2013 where C – C increased yield (Table 4.15). The results also showed significant decline in yield with time under C – C, emphasizing the necessity to alternate crops rather than continuous monoculture especially when no external nutrient inputs are used. On the other hand, the significantly higher grain yield under C – M can be attributed to its higher tendency to improve soil condition, thus, lower bulk density, enhance soil moisture content and storage, and SOC which binds and stabilizes loose soil aggregates. It is however important to note that these positive attributes (rotational benefits) are noticed with time as depicted by this study, which could also explain the no significant differences under C – M between the 2013 and 2014. The implication is that C - M is more able to improve the prevailing soil condition with time, thus, limiting the constraints and increasing grain yield. Meanwhile, haulm was significantly different in both years with higher values recorded under C – C and C – M in 2013 and 2014 respectively, similar to the trend of results of grain yield. The consistency in improved performace under C – M than C – C in 2014 also highlights the time effect on rotational benefits. From the results, it is likely that better performance under C – M in the latter year could be related to the inferred residual effect of mineral fertilizer applied to the maize crop in the sequence. Therefore, the impact of crop rotation on grain and biomass yield appears to suggest the type(s) of crops and duration of rotation as important factors. This is because while under maize C – M did not show any immediate significant impact on grain and stover yield, its effect under cowpea was significantly higher especially in the second year of practice.

The results of the study also showed higher values under mulch and no-mulch in 2013 and 2014 respectively, with significant differences observed in the latter year only. Mulching tends to increase soil moisture content and reduce compaction which creates a favourable soil condition for root development and good plant growth. In this study however, grain yield of cowpea under mulch was significantly lower than no-mulch but this effect was not immediate as higher value was noticed under mulch in the first year.

The tillage x crop rotation x mulching interactions differed significantly in their impact on cowpea grain and stover yields. The differences in the impact of treatment interactions varied between the two years of the study depending on the effects of the main factors. Thus, whereas the main effect may not be significant as in the case of grain yield under mulch in 2013, its interaction with other factors showed significant impact.

4.16.0 Profitability of the interactions of tillage, crop rotation and mulching using grain yield of maize and cowpea

4.16.1 Results

The profitability of the agronomic practices evaluated have been presented in Figure 3.3 and 3.4 for maize, and Figure 3.5 and 3.6 for cowpea. The returns on investment of maize in 2013 (Figure 3.3) was greater under treatment combinations that included tillage rotation, irrespective of crop rotation and crop residue management except under CT – NT/M – M/-R where VCR was less than 2. In 2014 however, profitability was generally low with most treatment combinations producing VCR < 2 except under CT – NT/C –

M/+R where VCR was greater than two (Figure 3.4).
The return on investment of cowpea production under the treatment combinations evaluated in 2013 was greater under CT – CT/C – M/+R, CT – CT/C – C/+R and CT – NT/C – C/-R (Figure 3.5). Thus, these practices produced a VCR > 2. The results also showed that irrespective of crop rotation, a treatment combination of tillage rotation with no mulch as under CT – NT/C – C/-R and CT – NT/ C – M/-R, produced a greater return on investment (VCR > 2) than the remaining practices in 2014 (Figure 3.6).

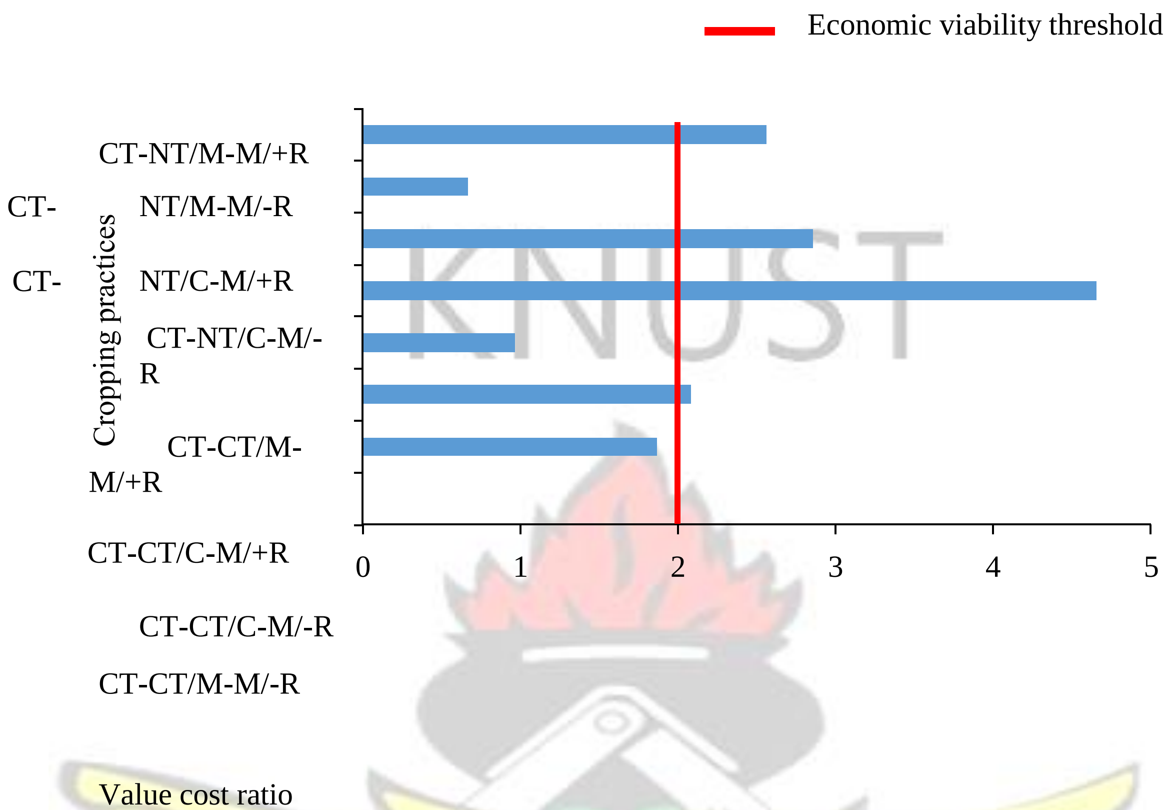

Figure 3.3: Value cost ratio of practice interactions for maize production 2013 cropping season

Cropping practices

CT-NT/M-M/+R

CT-NT/M-M/-R

CT-NT/C-M/+R

CT-NT/C-M/-R

CT-CT/M-M/+R

CT-CT/C-M/+R

CT-CT/C-M/-R

CT-CT/M-M/-R

Value cost ratio

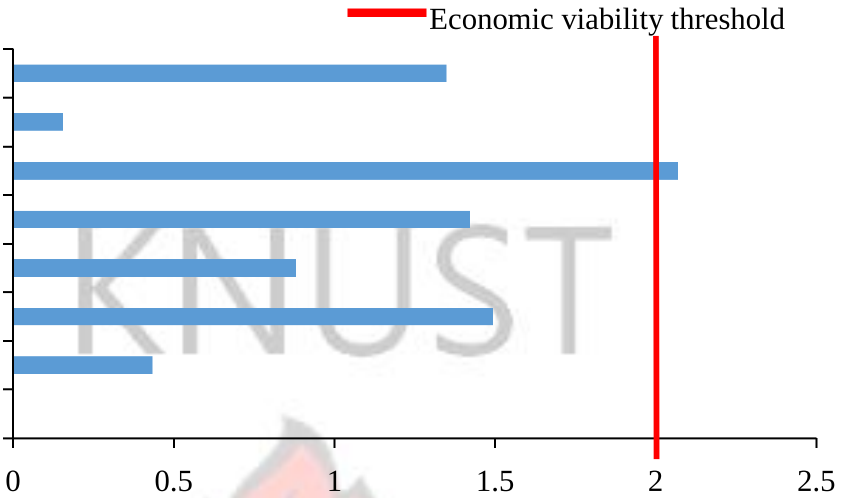

Figure 3.4: Value cost ratio of practice interactions for maize production 2014 cropping season

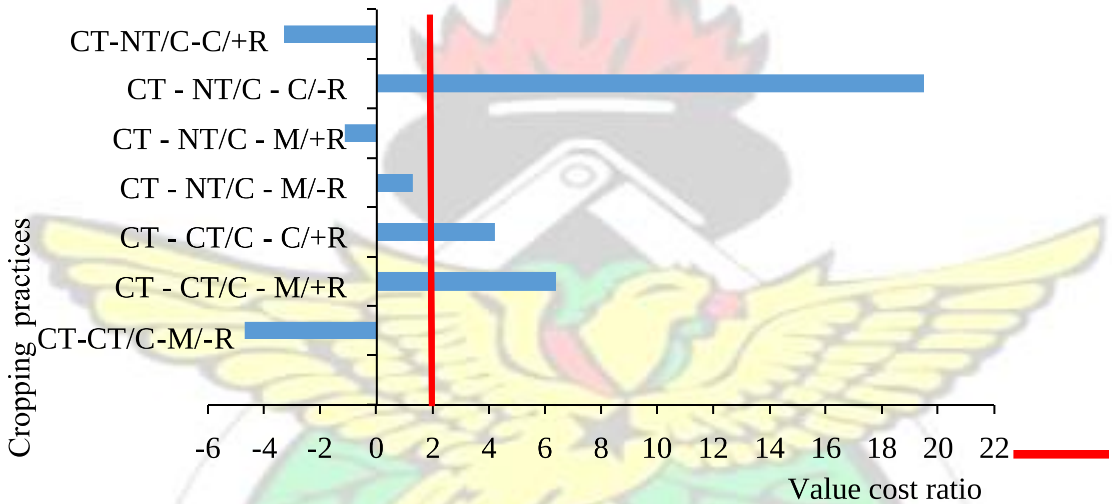

Figure 3.5: Value cost ratio of practice interactions for cowpea production in 2013 cropping season

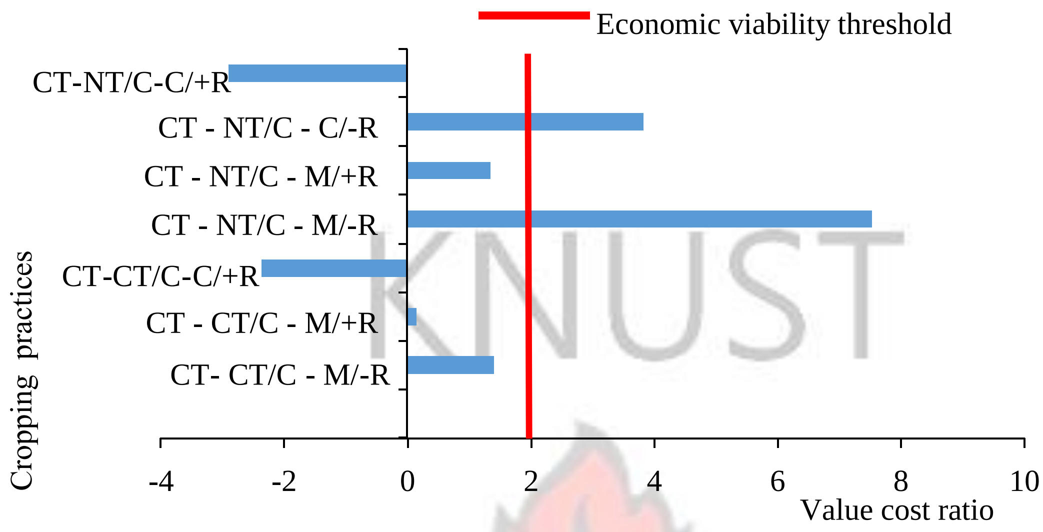

Figure 3.6: Value cost ratio of practice interactions for cowpea production in 2014 cropping season

4.16.2 Discussion

Crop production practices that do not give direct and or immediate return on investment are scarcely adopted by farmers (Okpara and Igwe, 2014). For farmers, increasing income levels supersedes social and environmental effects of their activities. It however important to be mindful of the fact that farmers also prefer improved production systems with sustained yield than those that give a one-time increased yield followed subsequently by poor productivity. Crop farmers are generally risk averse and may be unwilling to try out a practice until they are very certain of its impact. Economic evaluation of a new practice is required for farmers to appreciate the profitability of the practice.

In this study, different practice combinations were evaluated for their impact on selected soil physical and chemical properties, and crop yield. The overall outlook of the result suggests that compared to continuous conventional tillage, monoculture and no mulch, the use of conventional-no-tillage rotation, cowpea-maize rotation and mulch has the potential to enhance soil properties and increase crop yield. Though environmental and social effect assessments were not considered by this study, it can be deduced that the reduced soil disturbance, crop diversification and soil surface protection employed under the latter set of practices could assure of a sustainable practice. Meanwhile, one major setback to the sustainability of an agricultural practice is the non-adoption by farmers especially when the returns on investment is low.

The profitability of treatment combinations used in this study was inconsistent between the two years of study. This could be attributed to the variations in yield increase and product price with the cost of input remaining same under most instances. While in 2013, all treatment combinations under tillage rotation were profitable for maize production except CT – NT/M – M/-R, the reverse was observed under continuous conventional tillage where all the treatment combinations were unprofitable except CT – CT/C – M/+R. Meanwhile in 2014, apart from CT – NT/C – M/+R, none of the other treatment combinations under tillage rotation and continuous conventional tillage was profitable for maize production. The finding of this study suggests that the inclusion of cowpea-maize rotation and mulch could avert yield loss under continuous conventional tillage and even yield a better return under tillage rotation. The enhancement of soil properties and crop yield under such practice combinations give credence to their greater profitability. It is important to indicate that with the current spate of price increases (especially, cost of inputs), systems that include mulch may decrease profitability because of the higher labour required to store, cut and spread the crop residue. It is therefore important to enact and implement favourable policies to support farmer investment in practices that have the potential to protect the soil from degradation and increase return on investment.

With respect to cowpea production, the combination of continuous conventional tillage and mulch produced greater profitability (showing VCR > 2) than with no mulch in 2013. However, the observation did not recur in 2014 where all treatment combinations under continuous conventional tillage turned to be economically unprofitable (VCR < 2). Thus the profitability of a practice may vary with time and season indicating the need for regular economic assessment of agricultural practices. The variation in profitability may be negative or positive. In the case of the former, the practice could show a decrease in profitability or become unprofitable as noticed for treatment combinations under continuous conventional tillage. For treatment combinations under conventional-notillage rotation, profitability of cowpea production was greater with no mulch than with mulch in both years. The implication is that, under conventional-no-tillage rotation, residue retention will not enhance cowpea productivity. The foregoing appear to suggest that there is no need to invest in mulching under conventional-no-tillage rotation for cowpea production.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The study has contributed to the general objective of conserving soil resources and identifying beneficial soil management options for increased productivity under tillage, crop rotation and mulching systems by: evaluating the impact of tillage rotation, crop rotation and mulching on selected soil physical and hydro-physical properties; determining the impact of tillage rotation, crop rotation and mulching on organic carbon, particulate, extracted and mineralized carbon; and assessing the effect of tillage rotation, crop rotation and mulching on the yield of maize and cowpea.

i. Conventional-no-tillage rotation, cowpea-maize, mulch and their interactions enhanced soil physical and hydro-physical properties relative to continuous conventional tillage, cowpea monoculture and no-mulch. On the other hand, cowpea-maize rotation was in most cases not significantly ($P > 0.05$) different from maize monoculture, indicating that to improve soil physical and hydrophysical conditions, crops that return high amount of low quality biomass are as important as a rotation of high quality and high biomass producing crops. ii. Significant ($P < 0.05$) differences were observed in the impact of tillage, crop rotation, mulching and their interactions on organic carbon, particulate, water extractable and mineralized carbon. The treatment interations with mulch especially under conventional-no-tillage rotation and cowpea-maize rotation or maize monoculture recorded greater values of organic, particulate and water extractable carbon. On the other hand, higher mineralized carbon values were observed when continuous conventional tillage was involved in the interaction. This finding suggests that conventional-no-tillage rotation x cowpea-maize rotation or maize monoculture x mulch is vital for soil carbon management.

iii. Higher maize grain yield was produced under conventional-no-tillage rotation x cowpea-maize rotation or maize monoculture x mulch and under continuous conventional tillage when combined with cowpea-maize rotation and mulch. The impact of the former practices on cowpea grain yield was rather inconsistent though significantly ($P < 0.05$) higher grain yield was produced under conventional-no-tillage rotation, cowpea-maize rotation and no-mulch during the 2014 cropping season. The results suggest higher cowpea grain yield under nomulch than with mulch.

5.2 Conclusions

Based on the study hypothesis, the study hereby concludes that conventional-no-tillage rotation in combination with cowpea-maize rotation and mulch complementarily enhanced soil properties and increased maize grain and stover yield. However, the impact of tillage rotation x cowpea-maize rotation x mulch on soil properties was not always better than continuous conventional tillage especially when combined with cowpea-maize rotation and mulch. Also, cowpea grain yield was significantly ($P < 0.05$) higher under conventional-no-tillage rotation when combined with cowpea-maize rotation or cowpea monoculture with no-mulch than when mulched. Based on these inconsistencies in the impact of conventional-no-tillage rotation x cowpea-maize rotation x mulch, the hypothesis of this study that the interaction of the aforementioned practices will complementarily enhance soil properties and crop yield compared to continuous conventional tillage x monoculture and no-mulch is rejected. However, the combination of conventional-no-tillage rotation x cowpea-maize rotation x mulch has the potential to improve soil condition, promote sustainable soil management and enhance the grain yield of maize on Haplic Plinthosol in the semi-deciduous forest zone of Ghana. Also, on the basis of the specific objectives the following conclusions are drawn;

i. Conventional-no-tillage rotation, cowpea-maize rotation and mulch reduced the tendency for increase in soil bulk density, reduced penetration resistance and did not enhance saturated hydraulic conductivity except in the case of mulch. Conventional-no-tillage, cowpea-maize rotation and mulch increased total porosity, macroaggregate fraction and aggregate stability as well as sorptivity, steady state infiltrability, and cumulative water infiltration. Cumulative moisture stored with depth was significantly higher under mulch in both cropping years. ii. Soil carbon fractions (except mineralized carbon) were significantly higher under conventional-no-tillage rotation than continuous conventional tillage. However, soil carbon fractions including mineralized carbon (15 – 30 cm depth), were significantly higher under cowpea-maize rotation, maize monoculture and mulch than the other practices.

iii. Conventional-no-tillage rotation, cowpea-maize rotation and mulching significantly increased maize grain and stover yield but not cowpea grain and stover yield. Maize grain yield was consistently higher under CT –NT, C – M and

+R. However, the former and latter practices showed significant impacts only in

2014 with no differences noticed under crop rotation in both cropping years. On the other hand, grain yield of cowpea did not follow any consistent trend. Notwithstanding, CT – NT, C – M and –R significantly increased cowpea grain yield in 2014 cropping season.

5.3 Recommendations

Conventional-no-tillage rotation rather than continuous conventional tillage showed a greater potential to improve soil condition and sustain crop production in the semideciduous forest zone of Ghana. Hence, its combination with cowpea-maize rotation and mulching is recommended.

For further evaluation, the study recommends:

i. the assessment of conventional-conservation tillage, a combination of maize monoculture with intermittent cowpea rotation and mulching on the impact of soil physical and hydro-physical properties. ii. the measurement of carbon fractions under the set treatments in (i) above taking

into account the recalcitrant fraction.

iii. a repeat of the treatment combinations used in this study except for the mulch for which different rates can be used to evaluate its impact on grain yield of cowpea.

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APPENDICES

Appendix 1. Pearson's correlation of some initial soil chemical properties

	Organic carbon	pH
pH	-0.765 (0.235)	
Exchangeable acidity	-0.967 (0.033)	0.746 (0.254)

P < 0.05 in ()

Appendix 2. Regression of some initial soil chemical properties

Soil parameters	df	R^2	P value	Regression equation
Organic carbon versus total nitrogen	1	92.5	0.038	TN = - 0.0372 + 0.216 org C
Organic carbon versus available phosphorus	1	99.2	0.004	Av. P = - 19.0 + 20.0 org C
Organic carbon versus exchangeable potassium	1	66.1	0.187	K = - 0.052 + 0.172 org C

Appendix 3. Pearson's correlation of cowpea nutrient components

	%C	%P	%K	%TN
%P	0.809 (0.191)			
%K	0.983 (0.017)	0.904 (0.096)		
%TN	-0.986 (0.014)	-0.894 (0.106)	-1.000 (0.000)	
C:N	0.996 (0.004)	0.859 (0.141)	0.995 (0.005)	-0.997 (0.003)

Appendix 4. Regression of selected soil and plant properties

Parameters	df	R^2	Regression equation
Soil P versus Plant P	1	90.0	Plant P = 0.134 + 0.0129 soil P
Soil K versus Plant K	1	74.4	Plant K = 1.02 + 5.66 soil K

Appendix 5. Pearson's correlation of selected soil variables under tilage

	Penetration resistance (PR)	Total porosity (TP)	Organic carbon (OC)	Bulk density (BD)
TP	-0.303 (0.072)			
OC	0.176 (0.306)	0.110(0.521)		
BD	0.303 (0.072)	-1.000 (0.000)	-0.110 (0.521)	
Ks	-0.373 (0.025)	0.201(0.239)	0.010 (0.952)	-0.201 (0.239)

Appendix 6. Pearson's correlation of soil properties under crop rotation

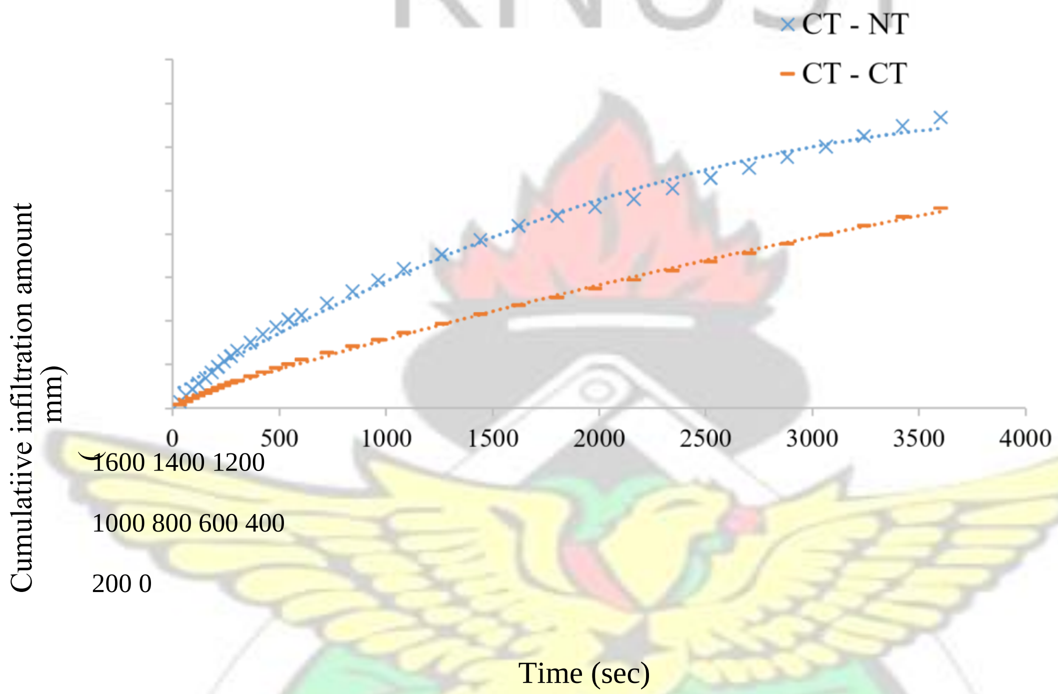
	Ks	BD	kPa	*f*
		Omankwa		
BD	-0.453 (0.139)			
kPa	-0.511 (0.090)	0.279 (0.380)		
f	0.453 (0.139)	-1.000 (0.000)	-0.279 (0.380)	
%C	-0.179 (0.577)	-0.026 (0.936)	0.079 (0.806)	0.026 (0.936)
		Asontem		
BD	0.865 (0.000)			
kPa	-0.027 (0.934)	0.254 (0.426)		
f	-0.865 (0.000)	-1.000 (0.000)	-0.254 (0.426)	
%C	-0.522 (0.082)	-0.251 (0.431)	0.515 (0.087)	0.251 (0.431)
		Rotation		
BD	-0.424 (0.170)			
kPa	-0.379 (0.225)	0.415 (0.180)		
f	0.424 (0.170)	-1.000 (0.000)	-0.415 (0.180)	
%C	0.691 (0.013)	-0.044 (0.891)	-0.218 (0.497)	0.044 (0.891)

kPa is penetration resistance, BD is bulk density, *f* is total porosity and %C is organic carbon

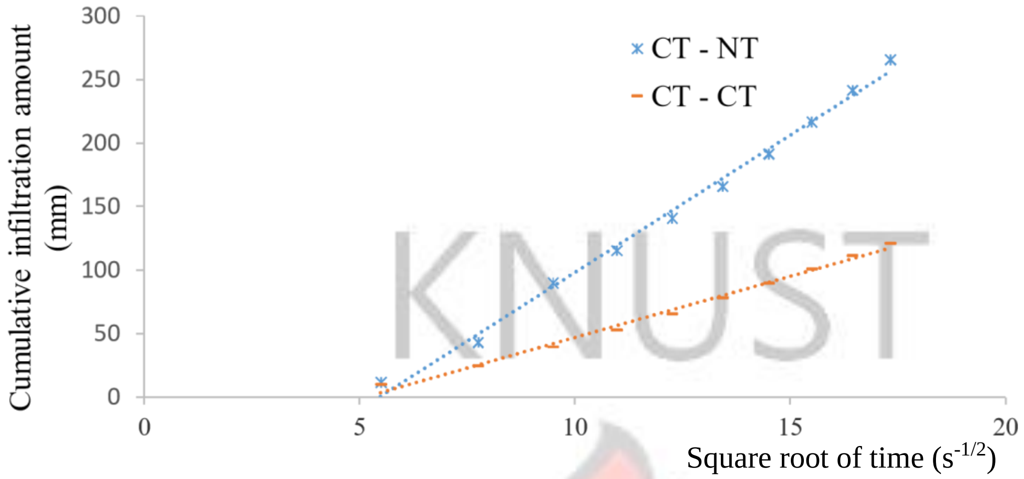
Appendix 7. Pearson's correlation of soil properties under mulching

	Ks	BD	kPa	*f*
		Mulch		
BD	-0.599 (0.039)			
kPa	-0.274 (0.389)	-0.054 (0.868)		
f	0.599 (0.039)	-1.000 (0.000)	0.054 (0.868)	
%C	0.145 (0.652)	-0.370 (0.237)	0.083 (0.798)	0.370 (0.237)
		No Mulch		
BD	-0.461 (0.132)			
kPa	-0.545 (0.067)	0.218 (0.496)		
f	0.461 (0.132)	-1.000 (0.000)	-0.218 (0.496)	

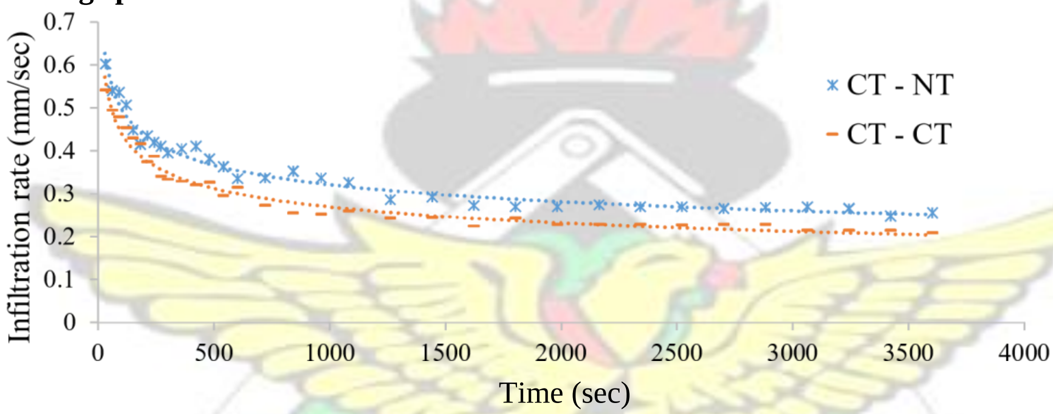
%C	-0.637 (0.026)	0.315 (0.230)	0.613 (0.034)	-0.375 (0.230)



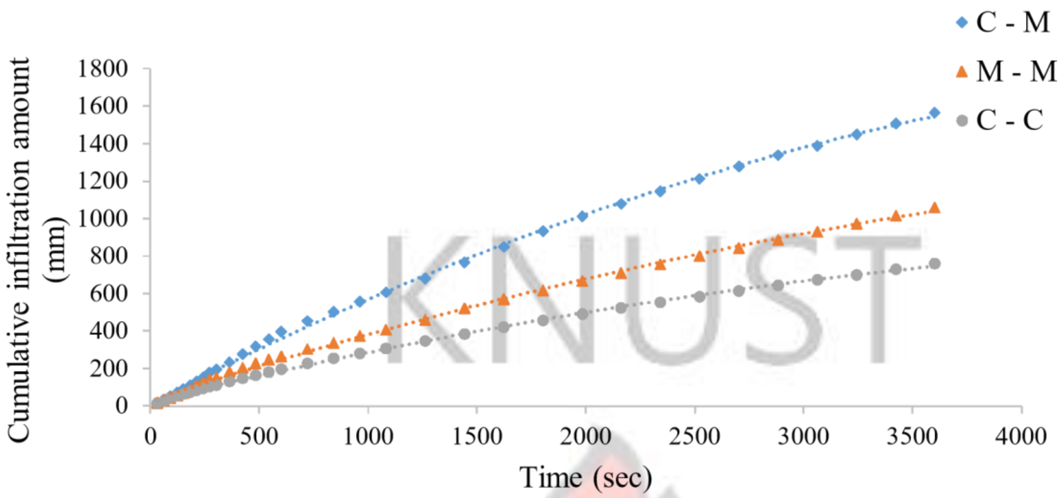
Appendix 8: A plot of cumulative infiltration amount against time under two tillage practices



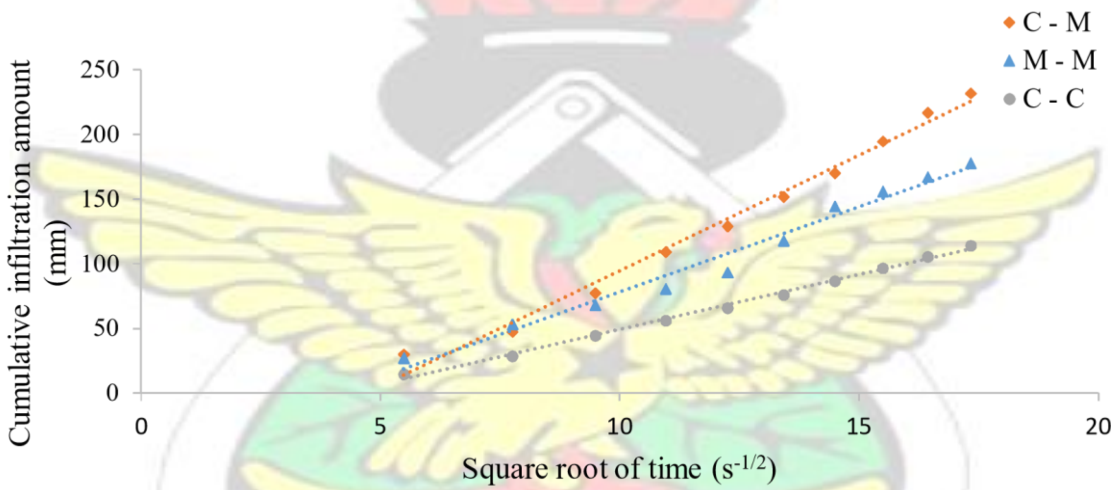
Appendix 9: A plot of cumulative infiltration amount against square root of time under two tillage practices.



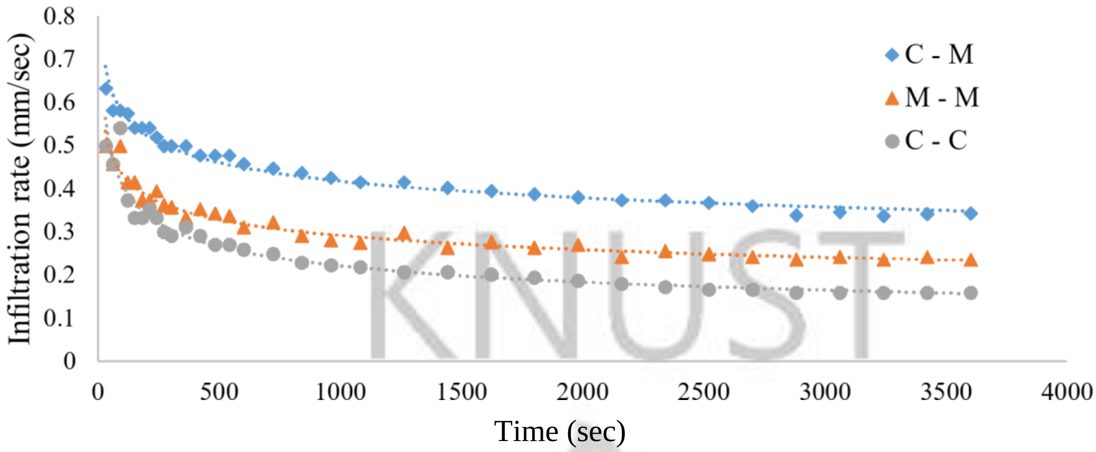
Appendix 10: A plot of infiltration amount against time under tillage practices



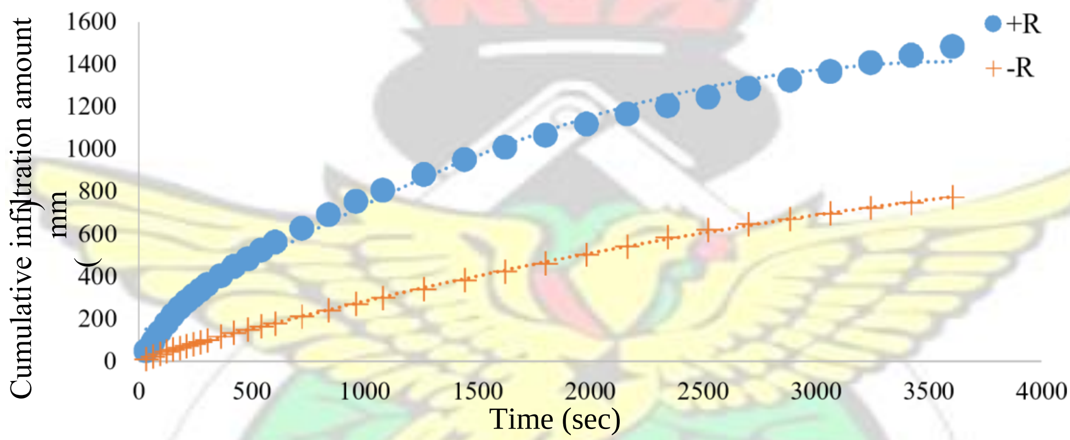
Appendix 11: A plot of cumulative infiltration amount against time under crop rotation practices



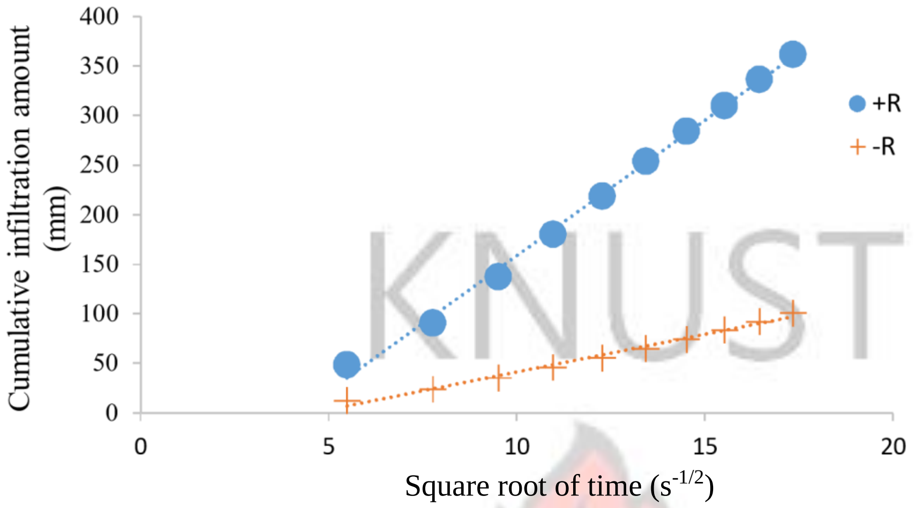
Appendix 12: A plot of cumulative infiltration amount against the square root of time under crop rotation practices



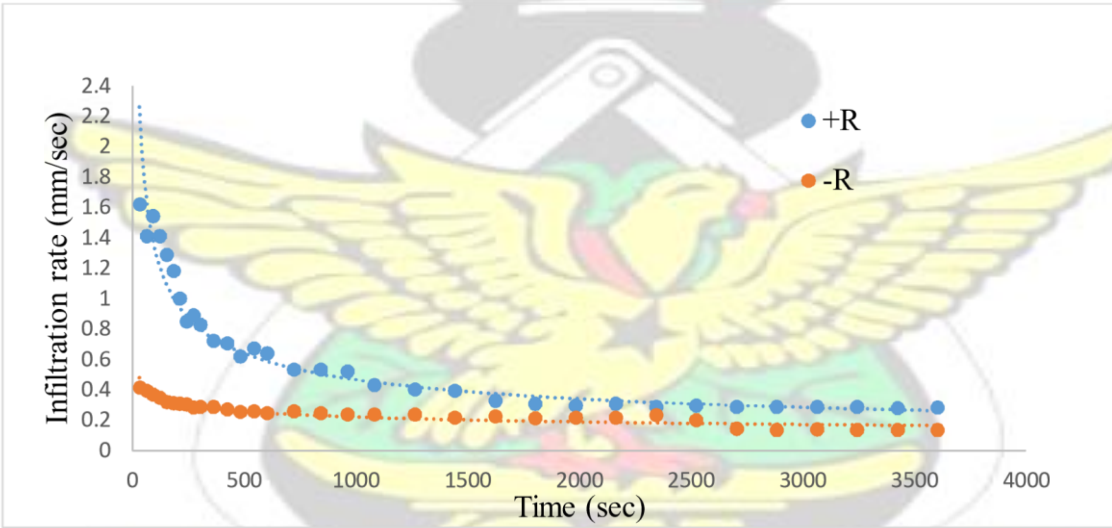
Appendix 13: A plot of infiltration rate against time under crop rotation practices



Appendix 14: A plot of cumulative infiltration amount against time under mulching practices



Appendix 15: A plot of cumulative infiltration amount against the square root of time under mulching practices



Appendix 16: A plot of infiltration amount against time under mulching practices Appendix 17. Summary of aggregate size distribution and stability measured by dry sieving from 0 – 30 cm soil depth

Practice	4 – 2	2 – 1	1 – 0.25	< 0.25	MWD (mm)
	……………………..%……………..		…………		
Tillage					
CT – CT	14.15	16.68	39.84	29.33	0.76
CT – NT	14.91	17.47	37.69	29.93	0.76
CV (%)	35.0	19.1	20.8	47.3	19.9
$LSD_{0.05}$	0.34	ns	ns	ns	ns
Crop rotation					
C – C	10.24	14.86	31.64	43.26	0.61
M – M	16.54	18.84	40.04	24.59	0.81
C – M	16.81	17.53	44.62	21.05	0.85
CV (%)	28.0	16.6	15.5	33.3	14.0
			Sieve size (mm)		
$LSD_{0.05}$	0.57	0.55	0.71	0.68	0.007
Mulching					
-R	11.46	15.49	36.52	36.53	0.68
CV (%)	27.6	16.8	20.1	40.8	17.2
+R	17.56	18.66	41.01	22.73	0.83
$LSD_{0.05}$	0.36	0.50	0.66	0.51	0.005
Interactions					
CT – CT/C – C/-R	7.01	14.59	25.76	52.64	0.51
CT– CT/ C-C/+R	11.72	16.96	21.88	39.45	0.65
CT– CT/M–M/-R	13.40	18.41	42.78	25.42	0.80
CT– CT/M–M/+R	19.62	17.78	46.49	16.11	0.90
CT– CT/C–M/-R	12.61	14.43	45.36	27.62	0.78
CT– CT/C–M/+R	20.53	17.92	46.80	14.76	0.92
CT – NT/C – C/-R	8.82	11.84	34.91	44.43	0.60
CT–NT/ C – C/+R	13.39	16.05	34.03	36.53	0.68
CT–NT/M–M/-R	13.02	17.59	30.19	39.21	0.65
CT–NT/M–M/+R	20.12	21.57	40.70	17.61	0.88
CT–NT/C–M/-R	13.91	16.08	40.15	29.87	0.75
CT–NT/C–M/+R	20.20	21.67	46.18	11.95	0.95

CT – CT is continuous conventional tillage, CT- NT is tillage rotation, C – C is cowpea monoculture, M – M is maize monoculture, C – M is cowpea-maize rotation, -R is no residue mulch, +R is residue mulch

Mean	14.53	17.07	38.77	29.63	0.76
CV (%)	22.2	13.7	13.8	26.0	10.9
$LSD_{0.05}$	0.87	1.09	1.95	1.58	0.01

retained, ns: not significant at F probability 0.05, CV is coefficient of variation and LSD is least significant difference, MWD is mean weight diameter.

Appendix 18. Aggregate size distribution and stability measured by wet sieving from 0 – 30 cm soil depth

	Sieve size (mm)				
	4 – 2	**2 – 1**	**1 – 0.25**	**< 0.25**	
Practice	……………………..…..%………..……………				**MWD (mm)**
Tillage					
CT – CT	13.48	16.16	35.75	34.70	0.70
CT – NT	14.63	15.45	38.01	31.90	0.73
CV (%)	35.5	23.5	19.3	37.8	18.9
$LSD_{0.05}$	ns	ns	ns	ns	ns
Cropping system					
C – C	8.99	13.96	31.15	45.90	0.58
M – M	17.06	16.63	40.25	26.70	0.80
C – M	15.96	16.84	39.25	27.95	0.78
CV (%)	24.5	22.1	16.1	26.3	13.1
$LSD_{0.05}$	1.88	2.06	4.39	4.11	0.04
Mulching					
-R	12.58	14.10	35.05	38.27	0.66
+R	15.43	17.51	38.72	28.34	0.77
CV (%)	34.2	20.8	18.9	34.8	17.4
$LSD_{0.05}$	0.80	1.02	0.67	1.20	0.01
Interactions					
CT – CT/C – C/-R	7.14	12.82	30.21	49.83	0.54
CT– CT/ C-C/+R	8.81	15.89	33.99	41.32	0.63
CT– CT/M–M/-R	14.48	15.01	36.31	34.20	0.71
CT– CT/M–M/+R	18.94	18.72	41.29	21.05	0.85
CT– CT/C–M/-R	14.43	15.71	35.23	34.62	0.70
CT– CT/C–M/+R	16.46	18.83	37.49	27.21	0.78
CT – NT/C – C/-R	8.84	11.81	29.18	50.18	0.53
CT–NT/ C – C/+R	11.18	15.32	31.22	42.28	0.62
CT–NT/M–M/-R	15.71	14.15	40.52	29.62	0.76
CT–NT/M–M/+R	19.10	18.63	42.88	19.39	0.87
CT–NT/C–M/-R	14.89	15.11	38.85	31.15	0.74

CT–NT/C–M/+R	18.07	17.69	45.43	18.81	0.87
Mean	14.00	15.81	36.88	33.30	0.72
CV (%)	26.0	22.8	16.5	25.4	12.7
$LSD_{0.05}$	2.94	2.81	6.27	5.73	0.06

CT – CT is continuous conventional tillage, CT – NT is tillage rotation, C – C is cowpea monoculture, M – M is maize monoculture, C – M is cowpea-maize rotation, -R is no residue mulch, +R is residue mulch retained, ns: not significant at F probability 0.05, CV is coefficient of variation and LSD is least significant difference, MWD is mean weight diameter.

Appendix 19. Regression equations of maize grain yield and soil parameters

Relationships	**R^2**	**$Prob_{0.05}$**
Yield = 1.30 + 0.058 cumulative moisture storage	28.0	0.008
Yield = 1.49 + 0.0460 Cumulative moisture storage + 0.0000459 Infiltration amount	60.1	< 0.001
Yield = 1.33 + 0.0572 cumulative moisture storage – 0.87 bulk density + 0.0289 total porosity	31.6	0.051
Yield = -0.41 + 0.00596 cumulative moisture storage + 0.0361 total porosity	31.0	0.020
Yield = 1.82 + 0.0396 cumulative moisture storage + 0.00489 infiltration amount – 1.37 bulk density + 0.0398 total porosity	67.3	< 0.001
Yield = 2.85 + 0.0281 cumulative moisture storage + 0.00575 infiltration amount – 1.90 bulk density + 0.0466 total porosity – 0.0272 saturated hydraulic conductivity + 0.09 MWD	69.9	< 0.001
Yield = - 2.36 + 4.06 SOC	51.2	< 0.001
Yield = 2.76 + 0.0857 WEC	43.9	< 0.001
Yield = 6.29 + 5.71 SOC + 2.02 mineralized carbon	57.6	< 0.001
Yield = 6.76 + 0.0372 cumulative moisture storage – 0.40 bulk density + 0.0495 total porosity + 0.000236 infiltration amount + 3.64 SOC + 2.05 mineralized carbon	74.4	< 0.001

Appendix 20. Correlation of soil properties under maize crop

	BD	PMC	SOC	POC	DOC	MWD	Ks	I	S	Ko	θm PMC
-0.192											
	0.368										
SOC	-0.416	0.397									
	0.043	0.055									
POC	-0.252	-0.009	0.707								
	0.234	0.967	0.001								
DOC	-0.200	0.205	0.785	0.898							
	0.348	0.337	0.001	0.001							
MWD	-0.391	0.339	0.758	0.637	0.692						
	0.059	0.106	0.001	0.001	0.001						
Ks	-0.206	-0.452	0.404	0.737	0.617	0.316					
	0.334	0.027	0.050	0.001	0.001	0.133					
I	0.042	0.374	0.786	0.711	0.828	0.697	0.403		0.847		
0.072	0.001	0.001	0.001	0.001	0.051						
S	0.035	0.030	0.693	0.681	0.740	0.654	0.534	0.857			

	0.871	0.891	0.001	0.001	0.001	0.001	0.007	0.001			
Ko	0.270	0.334	0.676	0.621	0.772	0.552	0.254	0.917	0.795		
	0.203	0.111	0.001	0.001	0.001	0.005	0.231	0.001	0.001		
θm	-0.260	0.450	0.424	0.125	0.224	0.620	-0.204	0.339	0.291	0.312	
0.219	0.027	0.039	0.560	0.293	0.001	0.340	0.106	0.168	0.138		
f	-0.382	0.178	0.756	0.763	0.725	0.646	0.383	0.617	0.669	0.573	0.447
0.065	0.406	0.001	0.001	0.001	0.001	0.064	0.001	0.001	0.003	0.029	

Correlation coefficient on top and significance ($P < 0.05$) below.

Appendix 21. Principal component anaylsis of soil parameters affecting maize yield

	PC1	PC2	PC3
Infiltration amount	0.37138	0.38425	-0.09668
Bulk density	-0.18917	**0.60481**	0.2164
Cumulative moisture	0.1276	0.01848	**-0.73485**
Water extractable C	0.4145	0.16215	0.09513
Mineralized C	-0.32821	0.28941	0.13329
Particulate OC	0.41127	0.07338	0.19473
Penetration resistance	-0.30061	-0.09979	0.02377
SOC	0.4025	-0.00024	-0.1927
Total porosity	0.09192	**-0.60018**	0.22293
Saturated hydraulic	0.31704	-0.02456	0.50168
Eigen values	4.791	1.528	1.303
% variance	47.91	15.28	13.03
Cumulative explanation	47.91	63.19	76.22

Appendix 22. Regression equations of cowpea grain yield and soil parameters

Relationships	R^2	$Prob_{0.05}$
Yield = 3.53 – 0.0165 cumulative moisture storage – 0.94 bulk density	5.4	0.557
Yield = 1.88 – 0.0153 cumulative moisture storage – 0.77 bulk density + total porosity	7.0	0.687
Yield = 3.43 – 0.0144 cmulative moisture storage – 1.8 bulk density + 0.0184 total porosity + 0.0568	15.8	0.483
Yield = 1.12 – 0.0257 cumulative moisture storage – 0.97 bulk density + 0.0290 total porosity + 0.0312 saturated hydraulic conductivity + 1.83 MWD	28.4	0.261
Yield = -2.92 – 0.0174 cumulative mositure storage + 0.52 bulk density + 0.0259 total porosity + 0.0324saturated hydraulic conductivity + 2.24 MWD + 0.00147 penetration resistance	46.9	0.064
Yield = - 3.33 – 0.0181 cumulative moisture storage + 0.6 bulk density + 0.0191 total porosity + 0.0541 saturated hydraulic conductivity + 3.33 MWD + 0.00143 penetration resistance – 0.00242 Infiltration amount	49.0	0.091
Yield = -2.37 – 0.0040 cumulative moisture storage – 0.00058 Inflitration amount + 2.21 bulk density + 0.0368 total porosity – 0.0091 saturated hydraulic conductivity + 2.01 MWD + 0.000468 penetration resistance – 0.31 SOC – 3.15 mineralizable carbon	73.2	0.008

Appendix 23. Correlations of soil properties under cowpea

	bd	MWD	Ks	amount	sorpt	stead	mm	tp	SOC	POC	DOC
MWD	-0.148										
	0.491										
Ks	0.291	0.235									
	0.168	0.269									
amount	0.041	0.821	0.536								
	0.850	0.001	0.007								
sorpt	0.210	0.661	0.602	0.846							
	0.325	0.001	0.002	0.001							

stead 0.140 0.827 0.585 0.925 0.836
0.515 0.001 0.003 0.001 0.001

mm -0.155 0.493 0.047 0.292 0.228 0.270 0.470
0.014 0.829 0.166 0.284 0.202

Tp -0.357 0.647 0.290 0.679 0.707 0.624 0.257
0.087 0.001 0.170 0.001 0.001 0.001 0.225

SOC -0.193 0.690 0.176 0.624 0.498 0.559 0.373 0.637
0.367 0.001 0.410 0.001 0.013 0.005 0.072 0.001

POC 0.002 0.633 0.735 0.794 0.736 0.790 0.351 0.679 0.704
0.991 0.001 0.001 0.001 0.001 0.001 0.093 0.001 0.001

DOC 0.011 0.624 0.549 0.768 0.652 0.734 0.351 0.651 0.821 0.906
0.959 0.001 0.005 0.001 0.001 0.001 0.092 0.001 0.001 0.001

PMC -0.163 0.174 -0.241 0.062 -0.238 0.142 0.266 -0.035 0.147 0.087 0.125
0.446 0.417 0.256 0.775 0.264 0.509 0.209 0.872 0.494 0.687 0.560

Appendix 24. Correlation of cowpea grain and haulm yield in 2013 and 2014 cropping seasons

Periods	**r**	**$P_{0.05}$**
2013	0.707	< 0.001
2014	0.736	< 0.001

Appendix 25. Principal component analysis of soil parameters affecting cowpea yield

	PC1	**PC2**	**PC3**
Infiltration amount	0.4592	0.17644	0.02243
Bulk density	-0.01189	0.08322	**-0.71299**
Cumulative moisture	0.23296	-0.41037	0.2206
Saturated hydraulic C	0.27774	0.47941	-0.30618
Aggregate stability	0.43244	0.02035	0.24704
SOC	0.42063	-0.20264	0.15089
Penetration resistance	-0.25259	0.34878	0.39964

POC	0.47905	0.12252	-0.10156
Mineralized C	0.01892	**-0.62095**	-0.30807
Eigen value	3.759	1.841	1.475
% variance	41.77	20.46	16.39
Cumulative explanation	41.77	62.23	78.62

Appendix 26. Root weight of maize and cowpea at 6 weeks after sowing in 2014

Root dry weight (g/plant)		
Maize	**Cowpea**	
4.63	1.09	
9.76	0.675	
2.78	0.69	
7.33	0.54	
3.93	0.55	
4.6	1.435	
8.76	0.75	
6.32	0.53	
5.41	0.865	
4.77	0.58	
8.24	0.285	
10.06	0.41	
2.44	0.83	
4.08	0.685	
6.24	0.83	
4.63	0.54	
6.62	0.485	
5.83	0.645	
6.94	0.42	
15.97	0.3	
6.66	0.67	
3.22	0.475	
8.02	0.41	
5.13	0.44	
Average = 6.348	Average = 0.6304	Percentage diff. = 90.07 %

Appendix 27. Rating of soil chemical properties

Rating

Parameter	Extremely acidic	Very strongly acidic	Strongly acidic	Moderately acidic	Slightly acidic
pH (1:2.5, soil:water)	4.0	4.5	5.0	5.5	6.0
	Very high	High	Medium	Low	Very low
Organic C (% of soil weight)	>20	10-20	4-10	2-4	<2
Total N (% of soil weight)	>1.0	0.5-1.0	0.2-0.5	0.1-0.2	<0.1
	High	Medium	Low		
Ex. Mg^{2+} ($cmol_{(+)}$ kg^{-1})	>0.5	0.2-0.5	<0.2		
Ex. K^{+} ($cmol_{(+)}$ kg^{-1})	>0.6		<0.2		
Av. P mg P kg^{-1} soil (Bray)	>50	50-15	<15		

Source: Landon (1991).