EFFECTS OF CROP ROTATIONS ON SELECTED SOIL PROPERTIES AND MAIZE *(ZEA MAYS)* YIELD UNDER CONSERVATION FARMING

by

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2016

DECLARATION

DECLARATION

I, Richard Sichone, do hereby declare that this dissertation is my own work and to the best of my knowledge has never been submitted for the award of a degree, diploma or other qualification to this or any other University.

Signature……………………………………………

Date……6/07/2017…………………………………

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CERTIFICATION OF APPROVAL

CERTIFICATION OF APPROVAL

The dissertation of Mr. RICHARD SICHONE is approved as fulfilling the requirements for the award of the degree of Master of Science in Integrated Soil Fertility Management by the University of Zambia.

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ABSTRACT

Crop rotation is known to affect the physical, chemical and biological soil properties. This farming system has shown to be effective at reducing the farmers' costs while increasing the yields in the long run and improving the fertility of their land. This study investigated selected crop rotations and their impact on selected soil chemical, physical and biological properties and maize *(Zea mays)* yield over time in conservation plots. Although crop rotations have positive effects on the soil, many of the rotation factors, processes and mechanisms responsible for increased yields and other benefits are not clearly understood and quantified. This study aimed at testing the impact of crop rotations on selected soil physical, chemical and biological properties and maize yield. The study was conducted in two phases: 1) A greenhouse experiment. 2). Sampling and characterization of soil samples collected from two sites at Golden Valley Agricultural Research Trust (GART) in Chisamba district of the Zambian agro-ecological zone II, GPS coordinates S14^{o} 57.488', E028^{o} 06.085'. The treatments were maize-cowpea and maize groundnut rotations and the fields were 4 and 10 years old respectively. Changes in soil properties due to crop rotations over time were determined. The results indicated significant differences in soil pH, potassium, soil organic carbon and microbial biomass in the older rotation (10 years old) of conservation farming practice. Micronutrients zinc and sulphur were significantly affected by crop rotation in both sites. The physical parameters porosity, bulk density, infiltration and plant available water were not affected in the four years old rotation. The study also showed no correlation among the number of nodules, nodule weight and the amount of nitrogen fixed. The maize-cowpea rotation however had the highest yield. Similar studies should be conducted in other agro-ecological zones of the country to validate these findings.

DEDICATION

This study is dedicated to my parents Mr. and Mrs. Sichone for being an inspiration to me and for being there for me in good and bad times.

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LIST OF ABBREVIATIONS AND ACRONYMS

CF	:	Conservation Farming
ISFM	:	Integrated Soil Fertility Management
GART	:	Golden Valley Agricultural Research Trust
GPS	:	Global Positioning System
IITA	:	International Institute of Tropical Agriculture
SARD-SC	:	Support to Agriculture Research for Development of strategic crops
IFAD	:	International Fund for Agriculture Development
JAICAF	:	Japan Association for International Collaboration of Agriculture & Forestry.
OXFAM	:	Oxford Committee for Famine Relief
CFU	:	Conservation Farming Unit
IPCC	:	International Panel on Climate Change
EU	:	European Union
INESCOR	:	Institute of Economic & Social Research
SOC	:	Soil Organic Carbon
SOM	:	Soil Organic Matter
SMB	:	Soil Microbial Biomass
BR	:	Basal Respiration
TN	:	Total Nitrogen
BNF	:	Biological Nitrogen Fixation
FAOSTAT	:	Food & Agriculture Organization Statistical Database
FAO	:	Food & Agriculture Organization
RCBD	:	Randomized Complete Block Design
MRI	:	Maize Research Institute
ASTM	:	American Society of Testing & Materials
HCL	:	Hydrochloric Acid
NaOH	:	Sodium Hydroxide
AAS	:	Atomic Absorption Spectrometry
CEC	:	Cation Exchange Capacity
SAS	:	Statistical Analysis System

LSD	:	Least Significance Difference
NPK	:	Nitrogen-Phosphorus-Potassium
CV	:	Coefficient of Variation
KG	:	Kilogram
HA	:	Hectare
ATP	:	Adenosine Triphosphate
MP	:	Maize Plot
GP	:	Groundnut Plot
OM	:	Organic Matter
CFU	:	Colony Forming Units
ANOVA	:	Analysis of variance
MEQ	:	Milli-equivalents
CMOL	:	Centimole
PPM	:	Parts per million
Mg	:	Milligrams
G	:	Gram
DF	:	Degrees of freedom
S	:	Sulphur
Fe	:	Zinc
P	:	Phosphorus
Cu	:	Copper
Mn	:	Manganese
Ca	:	Calcium
Al	:	Aluminium
K	:	Potassium
Na	:	Sodium
NH_3	:	Ammonia
NO_3^-	:	Nitrate
NH_4^+	:	Ammonium

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CHAPTER ONE: INTRODUCTION

1.1 Background

Agriculture is the engine of growth for most economies in Sub-Saharan Africa. It contributes at least 70 % of employment, 40 % of export earnings, 30 % of gross domestic product (GDP) and up to 30 % of foreign exchange earnings (IFAD, 2003). The agricultural sector in Zambia comprises of mainly small scale farmers mostly located in the remote parts of the country. Small holder farmers contribute for 79 % of; Zambia's 1.2 million metric ton annual food requirement (JAICAF, 2008). The average, maize productivity among these small holder farmers ranges between 1.2 and 1.6 metric tons per hectare against the potential of 5 and 10 metric tons for Open Pollinated Varieties (OPVs) and hybrid varieties, respectively (MACO/CSO/FSRP, 2008). The main challenges faced by these farmers includes low soil fertility, erratic rainfall and little or no access to farm inputs such as fertilizer, seeds and chemicals (OXFAM, 2013).

Conservation farming encompasses three basic principles of; minimum soil disturbance, residue retention and crop rotation (Thierfelder and Wall, 2009). However, small scale farmers, find it difficult to follow all the three principles. Conservation farming takes advantage of the natural ecological processes that conserve moisture, enhance soil fertility, improve soil structure, and reduce soil erosion and the presence of pests and diseases (Lal, 2006). Under conservation farming, the increased amount of crop residues improves the soil physical, chemical and biological characteristics which results in increased soil fertility and crop yields (Van straaten, 2007). Additionally conservation farming techniques have the potential of soil moisture retention and mitigation of intra-seasonal dry spells that often result in low productivity and crop failure, reduced soil evaporation and enable organic matter buildup which enhances water holding capacity of the soil (Lal, 2006). It is against this background that this study was conducted to assess the effects of crop rotation on selected soil chemical, physical and biological properties and maize yields under conservation farming.

1.2 Maize production trends in Zambia

Maize is an important crop for the southern and central Africa. During the 1960s, production volumes in Zambia were relatively low (Byerlee, 1997). The yields varied from 1 tonne or less per hectare, however in the early 1990's production volumes and planting area both increased as the government introduced chemical fertilizer subsidies; this generally started raising maize yields (JAICAF, 2008). In the past years, the Zambian government has been promoting the production of maize with poor crop husbandry which led to the depletion of soil fertility and a buildup of diseases and pests, as a result of mono cropping (JAICAF, 2008).

1.3 Statement of the problem

There is paucity of information on crop rotation and its effects on selected soil chemical, physical and biological properties and crop yields under conservation farming. The findings of this study could provide important information about the suitability of crop rotations in conservation farming and their effect on soil quality. Additionally the results will provide an understanding on the changes that take place in the soil that lead to increased maize yields in conservation farming.

1.4 Main Objective

The main objective of the study was to evaluate the effects of crop rotations on selected soil properties and maize yield under conservation farming.

1.5 Specific Objectives

1. To determine the effect of maize-groundnut and maize-cowpea rotation on selected soil chemical properties; soil reaction, available phosphorus, nitrogen, organic carbon, calcium, magnesium, sodium, potassium, zinc copper, manganese, iron, sulphur and cation exchange capacity.
2. To evaluate the effect of the maize-groundnut and maize-cowpea rotation on selected soil physical properties; total porosity, infiltration rate, plant available water, and bulk density.

3. To evaluate the effect of the maize-groundnut and maize-cowpea rotations on biological nitrogen fixation, nodule population, nodule weight, soil microbial biomass and counts.
4. To determine maize yields under rotation with groundnut and cowpea.

1.6 Hypotheses

It was hypothesized that:

a) Maize-groundnut and maize-cowpea rotations under conservation farming improves soil reaction, available phosphorus, nitrogen, organic carbon, calcium, magnesium, sodium, potassium, zinc copper, manganese, iron, sulphur and cation exchange capacity.
b) Maize-groundnut and maize-cowpea rotations under conservation farming reduce soil bulk density and enhance total porosity, infiltration rates and plant available water.
c) Maize-groundnut and maize-cowpea rotations under conservation farming increase biological nitrogen fixation of the legumes, soil microbial counts biomass.
d) Maize-groundnut and maize-cowpea rotations under conservation farming increase maize yields.

CHAPTER TWO: LITERATURE REVIEW

2.1 Conservation Farming

Conservation farming is a farming practice which aims at conserving soil and water, which leads to improved crop yields. This is achieved through minimum soil disturbance, rotating crops and maintaining surface cover (mulch) which minimize runoff and erosion and improve the conditions for plant establishment and growth (CFU, 2007a).

Conservation farming (CF), as practiced in Zambia, involves a package of several key practices which include: dry-season land preparation using minimum tillage methods; crop residue retention; seeding and input application in fixed planting stations; nitrogen-fixing crop rotations; and reduced but precise doses of mineral fertilizer (CFU, 2007a and 2007b). For hand hoe farmers, CF involves dry-season preparation of a precise grid of 15,850 permanent planting basins per hectare. The dimensions of each basin are 20 cm deep, 30 cm long and 20 cm wide. Unlike the conventional hand-hoe and plowing technologies, CF entail disturbing only about 15% of the soil where crops are planted (Haggblade *et al.,* 2011). For farmers with access to animal traction, CF technology involves dry-season ripping, normally with the locally developed Magoye Ripper. For large-scale commercial farmers, mechanized minimum tillage with leguminous crop rotations of soyabeans, green gram, and sunhemp completes the ladder of conservation farming technologies (Haggblade *et al.*, 2011).

Over the years prolonged and intensive conventional cultivation in sub Saharan Africa has led to substantial losses of productive soils through erosion and depletion of soil organic matter and nutrients (Smaling, 1993; Stoorvogel *et al.,* 1993). According to the IPCC (2007), agriculture is estimated to account for 20 % of anthropogenic greenhouse gases. For example, the use of inorganic mineral fertilizers, agricultural machinery for tillage practices and irrigation are associated with increased CO_2 emissions (Cairns *et al.,* 2012). Improved agronomic practices such as conservation farming have the potential to mitigate global warming through the reduced greenhouse gas emissions and increased carbon sequestration (EU, 2010). Farming systems such as conservation farming have been shown worldwide to improve soil chemical and physical properties thus increasing yields (CFU, 2007b; SWCS, 2003). Conservation farming has been shown to be effective at increasing crop yields. This improves farmer nutrition as it minimizes chances of crop failure in drought years and in the long run, improves the soil fertility (CFU, 2007b). Conservation farming aims to achieve sustainable and profitable agriculture. This improves social, economic and environmental outcomes through the three basic principles of minimal soil disturbance, permanent soil cover and crop rotations (CFU, 2007a). Islam (2006) recognized conservation farming as capable of addressing the world's growing food needs while simultaneously ameliorating soil degradation and moderating climate change.

Labour bottlenecks of land preparation, planting and weeding form a major constraint to small holder farm output (INESOR, 1999). For example, Semb and Robinson (1969) observed that dry season minimum tillage enabled farmers to plant early. This improved plant establishment and access to early season microbial nitrate production (nitrogen flush). During the four to six week period following the first rains, farmers usually prepare their land for planting followed by critical weeding. Conservation farming practices also improve soil fertility in a variety of ways. For example, CF concentrates organic matter and fertilizer in fixed planting stations, thus improving the soil structure and fertility in zones of immediate proximity to the planted crops – in basins or along rip lines. This ensures optimal crop benefits by breaking through pre-existing hoe pan or plow pan layers hence increasing water infiltration and root development while harvesting water in periods of dry spells (Thierfelder and Patrick, 2012).

Meanwhile, crop residue retention builds up soil organic matter, thus improving soil structure and water retention capacity, increasing the plant responsiveness to small targeted doses of mineral fertilizer. Leguminous crop rotations improve soil fertility through biological nitrogen fixation (Burris and Roberts, 1993). This is because during the four to six week period following the first rains, farmers usually prepare their land for planting followed by critical first weeding. However, under conservation farming, dry season minimum tillage allows spreading of peak labor demand and also time for other enterprises In addition, early planting results in improved plant establishment (CFU, 2007a).

Food security is a major problem to Sub-Sahara Africa. Among the main factors exacerbating food insecurity are low soil fertility, pests and diseases, social instability and poor governance. Despite increases in area under cultivation in sub-Sahara Africa, improved productivity still remains a lower as a result of low soil fertility (Zulu *et al.*, 2008). The promotion and adoption of farming systems such as conservation farming (CF) which are designed to enhance farm output and income has received particular attention as a means of accelerating economic development (CFU, 2007b).

2.2 Crop rotation

A crop rotation is a series of different crops planted in the same field following a defined order (Boddey *et al.* 2006; Thierfelder and Wall, 2009). It results in improved soil conditions accomplished by preserving or ameliorating soil biological, chemical and physical properties (Aziz *et al*., 2011). Contrary to crop rotation, mono-cropping associated with poor land management practices has no doubt resulted in rapid degradation of soil fertility in most of the soils in sub Saharan Africa (Peter, 2007).

Meanwhile, crop residue incorporation leads to soil organic matter buildup and impacts soil physical properties; rate of N mineralization, soil moisture, pH and soil erosion (Pan, 2003). Crop rotations helps in nutrient distribution in the soil profile resulting in the full exploitation of the root zone by crops with differing rooting depths (Giller *et al.*, 2009). A study by Traore *et al*. (2007) showed a significant impact of crop rotations on cotton and maize yield when a legume was included in the rotation.

Based on the same study, Traole *et al*. (2007) recommended maize fields to be rotated with legumes to lessen the dependence on mineral fertilizers. Although there are obvious effects of rotation on soil mineral status, particularly N, researchers have concluded that there is a rotation effect beyond that which can be explained by soil mineral status alone

(Riedell *et al.*, 2009). Other benefits from crop rotations are often little understood and seldom acknowledged in literature (Pan, 2003). SAF (2005) observed that despite there being a number of crop rotations, there is no single rotation that can optimize water and nutrient use, minimize disease and weed problems and most importantly optimize benefits. This is attributed to the fact that there are numerous types of crop rotations available, and a diverse of plant species which may have variable impact on the soil.

According to EU (2010) crop rotations can result in highly variable economic and environmental impacts. These impacts should be understood as the sum of the impacts of each of the crops in rotation and the impacts of the agricultural practices used on these crops. However, the same crop rotations can have beneficial or detrimental impacts on the environment, depending on the management practices chosen by the farmer (EU, 2010).

2.3 Effects of conservation farming on selected soil chemical properties

2.3.1 Soil Reaction

Studies have been done in many parts of the world to ascertain the effects of conservation farming on soil pH and different views have emerged. For example, Neugschwandtner *et al.* (2014) reported an increase in soil pH with depth from 0 to 20 cm in an eight years old conservation farming trial in Austria. This increase in pH was attributed to soil organic matter accumulation in the top layers of the soil which has a buffering effect.

In addition Amado *et al.* (1998) reported that the practice of conservation farming over many years results in increases in soil reaction because the soil recovers its natural pH buffering capacity due to soil organic matter accumulation. On the other hand decreases in pH have been reported as a result of organic acid production and microbial respiration during the decomposition of crop residues (Hulugalle and Weaver, 2005).

No till has been reported to have different effects on soil reaction. For example Lopez-Fando and Pardo (2009) reported a lower pH for no-till than for mould board ploughing in the uppermost soil layer in a 5 years trial. The authors attributed this to acidification of soils through processes such as mineralization of organic matter, nitrification of surface applied N fertilizers and root exudation of organic acids.

2.3.2 Soil Organic Carbon and Total Nitrogen

Soil organic carbon (SOC) is the primary source of plant nutrients which plays a critical role in nutrient cycling. It is positively correlated with levels of soil nutrients, water holding capacity, infiltration capacity, aggregate formation and soil health (Lal, 1997). McDaniel *et al*. (2013) examined the influence of rotation types and management practices on C and N dynamics. Adding legumes in rotation compared to a monoculture increased soil C by 3.6 % and total N by 5.3 % (McDaniel *et al*., 2013). Contrasting results have been reported by Reeves (1997) that crop rotation with manure application under continuous cropping results in soil organic carbon decline.

However, the author never indicated the rate and magnitude of the decline as affected by cropping and tillage system, climate and soil type. The importance of increased soil organic carbon (SOC) enhances improved soil physical properties, water conservation and increased available nutrients. Several authors have linked these improved soil conditions to ultimately lead to greater biomass and crop yield (Bauer and Black 1994; Berzsenyi *et al.*, 2000).

There is a critical limit of SOC concentrations below which the productive capacity of agriculture is compromised through the deterioration of soil physical properties and impairment of soil nutrient cycling mechanisms (Bauer and Black 1994; Loveland and Webb, 2003).

Proper adoption of crop rotation can result in an increase or maintenance of soil organic matter with respect to both the quantity and quality (Liu *et al*., 2006). Soil organic carbon (SOC) can be best preserved by rotation in combination with minimum soil disturbance and additions of chemical fertilizers (Liu *et al*., 2006). Soil organic matter help in the sequestering of soil carbon. Soderstrom *et al.* (2014) observed that changes in (SOC) stocks significantly influence the atmospheric C concentration.

Intensification of agriculture and land-use change from forest to croplands is generally known to deplete SOC stocks. The depletion is exacerbated through agricultural practices with low return of organic material and various mechanisms, such as oxidation / mineralization, leaching and erosion.

2.3.3 Available Phosphorus (P)

Phosphorus is the second most limiting macronutrient in most tropical soils. It is an essential element classified as a macronutrient because of the relatively large amounts required by plants (Fernando *et al.,* 2002). It plays key roles in photosynthesis, respiration, energy storage and transfer, cell division and in biological nitrogen fixation process. Edward *et al.* (1992) have reported conservation farming practices to increase the availability of soil phosphorus compared to conventional farming system. The high P in CF was attributed to a reduction in mixing of the phosphorus fertilizer in the soil leading to low phosphorus fixation. The phosphorus increase under conservation farming is attributed to the direct surface placement of crop residues that leads to the accumulation of soil organic matter (SOM) and microbial biomass near the surface (Fernando *et al.,* 2002).

The accumulation of soil phosphorus near the surface in no-till has been shown not to have any negative impact on crop production (Fernando *et al.*, 2002). Improvements in crop performance and subsequent yield increases in conservation farming have been suggested to depend on the fixation of nitrogen and the recycling of large amounts of organic matter (Busman *et al.,* 2009). This is the ultimate source of available phosphorus and other nutrients near the soil surface, where they are easily accessible to plant roots (Bunch, 2003). The same author suggest such systems to be sustainable and support good yields over time with low (P) or no applications of additional nutrients. Castro *et al*. (2005) showed that there was no consistent pattern in the distribution of nutrients with soil depth up to 30 cm on Rhodic ferralsol of southern Brazil except with P. This was based on nutrient uptake determination in maize and soybean leaves. The author found crop rotation to improve all soil chemical properties, especially in soybean compared to maize fields.

2.4 Influence of CF on selected physical properties

2.4.1 Soil Bulk Density and Total Porosity

Soil bulk density and porosity are inversely related, such that any farming practice that affects one, affects the other (Rasaily, 2012). The effect of tillage and residue management on soil bulk density is mainly confined to the topsoil (plough layer), than the deeper soil layers which generally exhibit similar densities either under reduced or conventional tillage (Verhulst *et al.*, 2010). Li *et al*. (2007) demonstrated the long-term effects of Zero tillage with residue retention and conventional tillage without residue retention on the soil in Northern China. The study showed the evolution of soil bulk density under different tillage systems over time. The first six years showed significantly lower values for soil bulk density in the top 20 cm depth under conventional treatment than under zero tillage. The high bulk density in the zero tillage treatments was attributed to lack of regular soil loosening.

However, results obtained in the subsequent five years indicated similar values of soil bulk density for the two treatments of zero tillage with residue retention and conventional tillage without residue retention. While in the last 2 years of the experiment, bulk density was slightly less in the zero tillage trial with residue retention treatment than in the conventional tillage. Soil bulk density depends on the number of years of zero tillage and crop residue retention (Li *et al.*, 2007). Reduced soil bulk density is attributed to increased organic carbon and biotic activity. Several authors have observed tillage methods to have little effects on soil density with a general consensus of lower bulk density layer in ploughed than in unploughed soils (McCalla, 1958; Unger, 1969).

Crop rotations contribute to the improvement of soil physical properties such as tilth and bulk density. Al-Kaisi *et al*. (2005) measured bulk density in different crop rotations under reduced tillage. Soil bulk density measured in the 0-15 and 15-30 cm layer showed significantly lower values in the smooth brome grass treatment than in the maize-soya beans-alfalfa treatment after 10 years of experimentation. These results indicated that crop residue retention improves soil physical properties such as bulk density.

2.4.2 Soil Aggregation

Soil aggregation refers to the binding together of soil particles into secondary units. When sufficiently stable, aggregates do not readily disperse and hence, are especially important for maintaining favorable water and air infiltration rates. They also result in good soil structure, which is important for good plant growth (Singh *et al.,* 1990). The binding substances for aggregates have mineral or organic origins. Mineral substances are particularly important in tropic and subtropical regions, where stable aggregates cemented by iron result in high water infiltration even after prolonged rainfall (Donahue *et al.,* 1977).

Organic substances that affect aggregation are derived from fungi, bacteria, actinomycetes, earthworms, and other forms through their feeding and other actions on plant materials (Donahue *et al.*, 1977). Plants themselves may directly affect aggregation through exudates from roots, leaves and stems. According to Donahue *et al.* (1977) aggregates formation leads to higher surface water infiltration than in intensively cultivated, poorly aggregated soil.

Blanco-Canqui *et al*. (2004) reported the effect of crop rotation on physical soil properties to vary depending on the individual crop grown. For example, some studies have shown the use of cover crops in a rotation to have the greatest effect on aggregation despite varying. Meanwhile, rotation have been shown to be dependant on the type of crop grown (Blanco-Canqui *et al.*, 1994). Similarly, Villami *et al.* (2006) observed that all legumes in all rotation sequences of winter cover crops under a no till system improved the stability of the aggregates.

Other improved soil properties included reduced bulk density and penetration resistance of the surface layer, and increased porosity and available soil water holding capacity (Villami *et al.,* 2006). Contrally Benjamin *et al.* (2008) found crop rotation not to affect the stability of the aggregates, despite an observed high organic matter content. There is no consistent evidence showing the effect of sole rotational practices on soil physical properties, in the short term. In the long term, the production, of organic matter may affect some physical soil properties, such as aggregate stability. According to Filho *et al*. (2002) the effects may vary according to the crop, type of rotation and soil type.

2.5 Influence of conservation farming on selected soil biological properties

2.5.1 Soil Microbial Biomass (SMB)

A population of microorganisms is collectively known as microbial biomass (Gupta, 1998). Soil microbial biomass (SMB) represents a small portion of the organic matter that is very dynamic and responds very quickly to soil management practices (Muchabi *et al.,* 2014). The size of microbial biomass in the surface soil ranges from 0.25 mg/g soil in sandy soil to about 1.10 mg/g soil in organic matter rich clay (Gupta, 1998). Soil microbial biomass plays an important role in the physical stabilization of the soil aggregates. It reflects the soil's ability to retain and cycle nutrients (carbon, nitrogen, phosphorus and sulphur) and organic matter (Gupta, 1998).

Anderson and Domsch (1980) found total soil nitrogen in the microbial biomass to range from 0.5 to 15.3 % with an average of approximately 5 % in 26 agricultural soils. This nitrogen becomes available to the aboveground community upon death and decay of the microbial cells. In disturbed soils, such as when grassland soils are initially cultivated, a decline in soil microbial biomass results in a release of large quantities of nitrogen which is available for plant uptake (Robert, 2000). The fixed nitrogen which is not incorporated into newly synthesized microbial cells or aboveground biomass is lost from the ecosystem. This is done through leaching to the underground or through runoff. This creates a potential for nitrogen pollution of surface and groundwater (Robert, 2000). Therefore, it is frequently useful to estimate the size of the soil microbial biomass and its stability. The different types of management practices that affects soil microbial biomass includes tillage, crop residue retention, crop rotation, fertilizer and pesticide application. Crop roots and residues improve soil fertility by stimulating soil microbial communities and improving soil aggregation (Rangarajan, 2012).

Balota *et al.* (2003) observed a microbial biomass increase of up to 103% under no till and concluded that tillage practices significantly influences soil microbial biomass. This is an indication that both tillage and crop rotation affect microbial immobilization of soil nutrients. The larger amount of C immobilized in microbial biomass indicated that soil organic matter under no till system provided higher levels of more labile C than conventional tillage systems.

Manipulating the diversity of cropping sequences can affect soils by affecting C levels. This is because of the differences in the chemical composition of organic residues that are added to soils (Beare *et al.*, 1994). The effects of management on soil physical and chemical properties, affects microbial biomass and important processes such as decomposition of organic matter and mediation of nutrient availability to plants. Despite microbial biomass being a small fraction of the soils, its drives nutrient mineralization providing a labile source of major plant nutrients (C, N, P and S) (Dick, 1992). Moreover, microbial biomass can be an early indicator of changes in soil management compared to total organic C and N, which are unresponsive over short periods (Powlson *et al.* 1987; Saffigna *et al.*, 1989). Thus, microbial biomass can be used to determine the level of degradation of a soil (Smith and Paul 1990; Sparling, 1997).

Earlier findings have shown that multiple crop rotations (Maize-Soyabeans-Wheat-Cowpea) have a substantial impact on Total microbial biomass (Cmic), Basal respiration (BR), specific maintenance respiration (qCO_2), total organic carbon (TC), active carbon (AC), total nitrogen (TN), aggregate stability (AS) and particulate organic matter (POM) except for total porosity (ft) at different depths of soil (Aziz *et al.*, 2011). The maize – soya beans - wheat-cowpea (CSWC) rotation had improved soil quality than continuous maize cropping system (CC) and maize - soya beans (CS). These results imply that multiple cropping systems could be more effective for maintaining and enhancing soil quality than sole-cropping systems. However research conducted in Brazil has shown no clear differences in soil microbial biomass content in the 0-10 cm layer between the reduced tillage and conventional fields after four years of conservation tillage **(**Nijsingh, 2007). The effects of conservation farming on SMB, therefore, varies and is mainly dependant on the amount, type and quality of crop residues retained to the soil.

2.5.2 Biological Nitrogen Fixation (BNF)

Biological nitrogen fixation is the biological assimilation of dinitrogen, N_2, the gaseous form of nitrogen that comprises 80 % of the atmosphere (Vance, 2001). Nitrogen in variable quantities is fixed into the soil through various microbes under favourable soil conditions (Panda, 2006). In nitrogen fixers, dinitrogen is reduced to ammonia (NH_3), which is quickly consumed in the synthesis of organic nitrogen compounds (Michael and Donald, 1987). According to Bottomley and Myrold (2007) an enzyme called nitrogenase catalyzes the breaking of the nitrogen bonds and the addition of three hydrogen atoms to each nitrogen atom.

According to Jarecki and Lal (2003), including leguminous plants in crop rotations increases the N pool through symbiotically fixed N. A group of bacteria (Rhizobium) in symbiotic relationship with the host plant (legume) survives in the roots and fixes nitrogen in the root nodules. Reduced dependence on nitrogen fertilizer and adopting farming practices that favours the more economically prudent nitrogen fixation benefits for both agriculture and the environment (Vance, 2001). Legumes such as alfalfa, soya beans, edible beans and clover beans, form a symbiosis with α-proteobacteria of the order Rhizobiales including species of Rhizobium, Bradyrhizobium, Sinorhizobium, Azorhizobium and Mesorbizobium (Moravec *et al.,* 2011).

However, the process of establishing a symbiotic relationship is considered to be highly specific in that a specific bacteria species has one or a limited number of legume host species. For instance, *rhizhobium* for soya beans and alfalfa are *Bradyrhizhobium japonicum* and *Sinorhizobium meliloti* respectively. Further, the legume-rhizobium symbiotic relation is greatly influenced by farm practices (Unkovich *et al.,* 2008) and environmental stresses. Gupta (1998) noted that environmental stresses affects both the *rhizobium* and the host plant through soil acidity, extreme temperature, insufficient or excess soil moisture, nutrient deficiency (K, P, Ca, Mg, Mo, B), amount of N in the soil and inadequate photosynthesis.

2.5.3 Maize Crop

Maize *(Zea mays)* is one of the main cereal crops grown under conservation farming (Bonsu and Asibuo, 1996). It is rotated with a wide range of legume crops such as groundnuts *(Arachis hypogaea),* cowpeas *(Vigna unguiculata),* soya beans *(Glycine max)* and field beans *(Phaseolus vulgaris)*. Maize is produced on nearly 100 million hectares of land in the developing world, with almost 70% of the total maize production in the developing world coming from low and lower middle income countries (FAOSTAT, 2010). Moreover maize production is dominated by small holder farmers using traditional farming methods.

These involve fraught with drudgery and use of simple low input technology which results in low land and labour productivity (FAO, 1999). According to Rosegrant *et al*. (2008) the demand for maize by 2050 will double in the developing world. It has been predicted that maize will become the crop with the greatest production globally. The agricultural sector in Zambia supports livelihoods of 85 % of the population, with maize as the principal cash and staple crop (Chikowo, 2012). Maize yields from conservation farming fields vary from farmer to farmer and this can be attributed to farmers not following the procedures or principles of conservation. Studies have been done to show how maize yields are affected by conservation farming practices (Nadia *et al.*, 2004).

Nyamangara *et al.* (2013) reported that conservation farming where basins were used improved maize yield compared to conventional farming. Conservation farming practices combined with the use of both organic and mineral fertilizers improves maize yields compared to conventional farming (Rockstrom *et al.,* 2008). Conservation farming contributes currently one of the major keys to increasing crop yield and productivity in Zambia (Kabamba & Muimba, 2009).

Additionally Simunji (2014) also reported that maize-cowpea rotation under conservation farming increased maize grain yield and he further noted that maize grain yield varies with cowpea varieties used in a rotation. Challenges for the future adoption of conservation farming in sub-Saharan Africa includes improving farmers awareness of conservation farming benefits and how to efficiently incorporate green manure / cover crops and manage weeds (Kabamba & Muimba, 2009). Although several studies have shown that there are better yields performance, conservation alone does not adequately address the production challenges in the small holder farming systems (Nyagumbo, 2008).

CHAPTER THREE: MATERIALS AND METHODS

The study was conducted in two parts; the first part was a field activity which involved the analysis and comparison of soils collected from fields under conservation farming. The second part was a greenhouse experiment for the determination of biological nitrogen fixation using the Total Nitrogen Difference Method.

3.1 Site Characterization

The soil were collected from the Golden Valley Agricultural Research Trust (GART), in Chisamba of Chibombo District in Central Province. Chisamba is in agro-ecological region II of Zambia. This region receives between 800 and 1000 mm rainfall per annum. Chisamba area (average altitude: 1060 m) receives an average annual rainfall of 900 mm. The site / area has well drained very deep, dark red to reddish brown friable, clayey to fine to fine loamy soil with a humic top soil classified as alfisols with an average pH of 5.5. This site was chosen for this study because of several prior researches and similar ongoing studies at the site on conservation farming and agriculture.

3.2 0 Treatments and experimental designs

3.2.1 Site 1

This site had a 10 year old maize groundnut rotation comprising the following treatments.

1. Crop rotation without fertilizer.
2. Crop rotation with fertilizer
3. Mono-cropping without fertilizer.
4. Mono-cropping with fertilizer.

The fertilizer treatment included, 100kg per hectare D. compound; NPK 10-20-10 + 6.5 % S as basal dressing. These treatments were planted in permanent planting basins arranged in a randomized complete block design (RCBD) and replicated three times.

Seeds of commonly planted maize (MRI 514) and groundnut (MGV 4) varieties were sworn according to CF practices (CFU, 2007a). The baseline soil properties of this site are shown in table 1.

Table 1: Baseline soil properties of the maize-groundnut rotation site

Sampling Depth (cm)	pH ($CaCl_2$)	N %	OM %	P mg/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg
0 - 20	4.33	0.18	3.36	1.09	0.23	5.91	8.30

3.2.2 Site 2

At the time of this study, the site was in 4^{th} year of maize-cowpea rotation with two treatments of zero and half rate fertilizer application (100 kg per hectare D. compound) replicated four times. In this study, the cowpea variety Lutembwe was rotated with MRI 514. The number of rows per plot was 4 while the row length was 3 m and width 0.9 m. The seed rates were 13 kg and 0.5 kg for cowpea and maize respectively. The baseline soil properties of this site are shown in table 2

Table 2: Baseline soil properties of the maize-cowpea rotation site

Sampling Depth (cm)	pH	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)
0 - 20	5.2	6.67	4.39	0.28	0.07

3.2.3 Soil Sampling

Soil samples were collected from the two rotation plots. The soil was collected using a standard soil auger. Sampling was done from the permanent planting basins at a depth of 0-20 cm. Eight permanent planting basins from each experimental unit were randomly selected and sampled to constitute a composite sample. The composite soil sample was thoroughly mixed and unwanted materials present were removed and then 500 grams of soil was obtained for the analysis of selected chemical parameters. The same quantity was obtained for the analysis of microbial parameters. The soil for the microbial analysis was packed in a cooler box with ice kept at 4 ^{o}C before transportation until analysis. Undisturbed soil samples using core ring samples were also obtained from each experimental unit for the analysis of physical parameters.

Soil samples were subjected to chemical characterization after sieving through a 2 mm sieve. Bulk soils were also collected for the pot experiment in the greenhouse for the determination of biological nitrogen fixation.

3.2.4 Characterization of soil samples

Chemical soil properties.

The chemical soil properties that were analyzed for were as follows:

3.2.5 Soil Reaction (pH)

The soil pH was determined using the procedure of ASTM (1995). Ten grams of air dried soil was weighed into 50 ml beakers to which 25 ml of 0.01 M calcium chloride ($CaCl_2$) was added and equilibrated for 30 minutes using a mechanical shaker. The pH meter was standardized using buffer solutions of pH 4.0 and 7.0 prior to taking the readings. The soil pH was then determined after 30 minutes of equilibrating.

3.2.6 Soil Organic Carbon

Soil organic carbon was determined using the procedure of Walkley and Black (1934). One gram of air dried soil was weighed into 250 ml conical flask and 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) was added followed by 20 ml of concentrated sulphuric acid. The solution was swirled and allowed to stand for 30 minutes in the fume hood after which 150 ml of distilled water was added followed by 10 ml of phosphoric acid (H_3PO_4). Then 1 ml of diphenylamine indicator was added and the solution titrated with iron II sulphate ($FeSO_4$). A blank titration was carried out to standardize the dichromate solution. Percentage organic carbon was calculated using the formula;

% C = (a – b) x 0.4 where a = $FeSO_4$ added to the blank, b = $FeSO_4$ added to the sample. Assuming OM consisted 50 % C, percentage OM was calculated as % C x 2.

3.2.7 Total Nitrogen

Total nitrogen was determine using the procedure of Bremner (1996). One gram soil sample was weighed into 500 ml Kjeldahl flask to which 10 ml of concentrated sulphuric acid was added and swirled thoroughly. Three grams of a catalyst mixture (10 g Potassium Sulphate, 10 g Copper II Sulphate and 1 g Selenium powder) were then added to the Kjeldahl. The mixture was heated until frothing ceased. After digestion, gentle boiling continued for one hour and it was allowed to cool. The digest was carefully transferred into another clean Kjeldahl flask (750 ml). Twenty five milliliters of boric acid (H_3BO_3) indicator solution was added into the Erlenmeyer flask that was then placed under the outlet of the distillation apparatus.

Fifteen milliliters of 10 M sodium hydroxide (NaOH) was gently added into the distillation flask and quickly attached the Kjeldahl flask to the distillation apparatus and commenced the distillation. The condenser was kept cool allowing sufficient cold water to flow through and regulate temperature so as to minimize frothing and prevent flow back. The distillation continued for 15 minutes until distillate was collected for titration with 0.01 M standard hydrochloric acid (HCl). A blank was made using 0.03 g of pure starch. Percentage total nitrogen was calculated as;

$$\text{Total N (\%)} = \frac{\text{volume sample (ml)} - \text{volume blank (ml)} \times \text{normality acid} \times 1.4 \times 10}{\text{mass of sample}} \quad (1)$$

3.2.8 Total sulphur

The turbidmetric method as described by Butters and chenery (1959) was used in determining sulphur. Ten grams of air dried sieved soil was weighed and put into a 50 ml Erlenmeyer flask. Then 25 ml of acidified ammonium acetate extractant was added and shakened for 30 minutes at 200 oscillations per minute. After shaking the solution was filtered through a sulphate free filter paper (Watman No. 42 or equivalent). Within the interval of 3 to 8 minutes, the transmittance or optical density was read using a spectrophotometer, at a wavelength of 420 nm. Based on a 10 g sample of soil, 25 ml of extracting solution and a 10 ml aliquot:

The amount of sulphur was calculated as:

$$\mathbf{MgSO_4 - Skg\ of\ soil = \frac{{}^{mgS}/_{L}\ x\ 0.025L}{0.010\ kg\ soil} = mg\frac{S}{L}\ x\ 2.5} \qquad (2)$$

3.2.9 Exchangeable bases (K^+, Na^+, $Ca^{2+,}$ $Mg^{2+)}$

The exchangeable bases were determined using the procedure of schollenberger and Simon (1945). Ten grams of air dried soil sample in replicates of four was weighed into 100 ml beaker and 50 ml of ammonium acetate (NH_4Oac) buffered at pH 7.0 was added to each beaker then equilibrated for 30 minutes. The mixture was filtered and the filtrate was then used to determine the amount of K^+ and Na^+ ions in the soil. For the determination of Ca^{2+} and Mg^{2+} ions, 20 cm^3 of 5000 mg/cm^{-3} strontium solution was added to the 100 cm^3 volumetric flask containing 10 cm^3 of the filtrate and made up to the volume with NH_4O_{ac} extracting solution. Calcium and magnesium ions were then determined using the Atomic Absorption Spectrometry (AAS). Prior to reading the soil samples, the atomic absorption spectrometry machine was calibrated using the blank (distilled water). The amount of exchangeable bases was calculated using the formula below and expressed in cmo/kg^{-1} soil:

$$\text{Base} = \text{reading}\left(\frac{\text{mg}}{\text{L}}\right) \text{ x } \frac{\text{volume extract (L)}}{\text{equivalent weight of ion}} \text{ x dilution factor x } \frac{1000\left(\frac{\text{g}}{\text{kg}}\right)}{\text{weight of sample}}$$

(3)

3.2.10 Cation Exchange Capacity (CEC)

The cation exchange capacity was determined using the procedure of schollenberger and Simon (1945). The Cation Exchange Capacity is the amount of exchangeable cations per unit weight of soil. It is measured in milli-equivalents of cations per 100 g of soil. In the new SI units, this quantity is expressed in milli-mole percent. The sum of the exchangeable bases (K^+ + Na^+ + Ca^{2+} + Mg^{2+} + H^++ Al^{3+}) is the effective C.E.C of the soil.

The base saturation of a soil is the ratio of the exchangeable cations, which serve as plant nutrients, to the effective C.E.C of the soil.

$$\text{Base saturation} = \frac{(K^+ + Na^+ + Mg^{2+} + Ca^{2+})}{\text{Effective C.E.C}} \text{ x } 100$$

(4)

3.2.11 Available Phosphorus

The available phosphorus was determined following the procedure of Bray and Kurtz (1945). Three grams of air dried soil was weighed into 15 ml beakers to which 21 ml of extracting solution was added and allowed to equilibrate on a mechanical shaker for 1 minute. Five milliliters of the supernatant were pipetted into 25 ml volumetric flasks and 10 ml of distilled water was added followed by 4 ml of reagent B (1.056 g Ascorbic acid dissolved in 200 cm^3 of a mixture of 12 g Ammonium Molybdate in 250 cm^3 distilled water, 0.2908 g potassium Antimony Tartrate in 100 cm^3 distilled water and 2.5 M sulphuric acid) and up to volume with distilled water. The solution was allowed to develop colour for 15 minutes and P content in the samples was read on the Spectrophotometer at 882 nm. The plant available phosphorus was calculated as follows;

$$\mathbf{P}\left(\frac{\mathbf{mg}}{\mathbf{kg}}\right) = \mathbf{reading}\left(\frac{\mathbf{mg}}{\mathbf{l}}\right)\mathbf{x}\ \frac{\mathbf{extract\ (ml)}}{\mathbf{1000\ ml}}\ \mathbf{x}\ \frac{\frac{\mathbf{1000g}}{\mathbf{kg}}}{\mathbf{mass\ of\ sample\ (g)}}\ \mathbf{x\ dilution\ factor} \qquad (5)$$

Physical soil properties:

The physical soil properties that were analyzed for were as follows:

3.2.12 Soil Bulk Density and Total Porosity

Soil bulk density was determined by the core ring method as described by Hillel (1982). Undisturbed soil samples were collected from the field using core rings. The samples were oven dried at 105^{o}C for 24 hours and allowed to cool. The soil samples were there after weighed to determine the oven dry mass. Soil bulk density was then calculated using the formula below:

$$\mathbf{Soil\ bulk\ density} = \frac{\mathbf{Mass\ of\ oven\ dry\ soil}}{\mathbf{Total\ volume\ (solids+pore\ space)}} \qquad (6)$$

Total volume was taken as the volume of the core ring. Taking soil particle density as 2.65 g/cm^3, percentage total porosity was calculated as:

$$\mathbf{Total\ porosity}\ (\%) = \left(\mathbf{1} - \frac{\mathbf{Soil\ particle\ density}}{\mathbf{Soil\ bulk\ density}}\right)\mathbf{x\ 100} \qquad (7)$$

3.2.13 Plant available water

The plant available water which is the difference of water held at field capacity (0.1bar) and wilting point (15 bar) was determined using the procedure described by Hillel (1982). Samples with undisturbed structure were collected in volumetric rings (core rings) from a depth of 0-20. The soil samples were saturated and then subjected to tensions of 2 kPa in suction units and to tensions of 33 kPa using pressure plate apparatus. After equilibrium of the samples at the respective tension, they were dried in an oven at 105 ^{o}C to constant dry mass. The gravimetric moisture (g g^{-1}) were calculated according to Bruno *et al*. (2013) and subsequently the volumetric water content (q) corresponding to the potential.

3.2.14 Infiltration rates

The infiltration rates were determined using the mini disc infiltrometer as described by Hillel (1982). Good hydraulic contact between the infiltrometer disk and the infiltration surface of the soil sample in the core rings was maintained for correct measurement. The infiltrometer was filled with water, starting with the bubbling chamber and then filling the water reservoir tube. The initial water level in the reservoir tube was recorded, and then the infiltrometer tube was placed on the surface, and the stopwatch was started to record the time. The water level was recorded at regular time intervals. The infiltration rate is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of water layer that can enter the soil in a given time (Hillel, 1982).

Biological soil properties

The biological soil properties that were analyzed for are as follows

3.2.15 Soil Microbial Biomass

The soil microbial biomass was determined following the procedure of Kassem and Nannipieri (1995). The soils were sieved through an 8 mm sieve to remove unwanted materials such as stones and undecomposed debris. Fifty gram samples were weighed into 100 ml metal containers and moistened. The metal containers were then placed into two separate desiccators. A glass beaker containing 40 ml of ethanol-free chloroform ($CHCl_3$) and ceramic boiling chips was used in one of the desiccators and fumigated. The other desiccator was not treated and was used as a control. The soil samples were then incubated for 72 hours at room temperature (20 ^{o}C).

After fumigation, the chloroform was removed and the samples were allowed to stand for 15 minutes. The fumigated and unfumigated samples were then transferred into plastic containers each containing 5 ml of 1 M potassium hydroxide (KOH) in 50 ml beaker and a thin film of distilled water at the bottom. The fumigated soil samples were remoistened with a thin suspension of soil colloids as a microbial inoculum. The inoculum was prepared by shaking 10 grams soil in 100 ml distilled water. The fumigated and unfumigated samples together with two 2 blanks were incubated for 7 days at room temperature. After 10 days the samples were removed and the base trap (KOH) was titrated with 1 M HCl from which the CO_2 evolved was calculated. Soil respiration was equivalent to the CO_2-C evolved from the unfumigated soil. Assuming that the size of the soil microbial biomass was equivalent to the CO_2 evolved after incubating fumigated soils Kassem and Nannipieri (1995). Soil microbial biomass was estimated in mg C/g soil per day.

Microbial biomass-C = (CO_2- fumigated soil – CO_2-C unfumigated soil) / 0.45

Where 0.45 is the standard correction factor.

3.2.16 Microbial Counts

The standard plate count method was used in determining the number of bacterial cells according to Robert (2000). The serial dilutions of the broth culture were prepared. The nutrient broth in the tubes was mixed before each serial transfer. Volumes of 0.1 ml of the final three dilutions (10^{-5}, 10^{-6} and 10^{-7}) were transferred to duplicate nutrient agar plates, and labeled. Then 0.1 ml inoculum was spread evenly over the entire surface of one of the nutrient agar plates until the medium no longer appeared moist. Then flaming and spreading for each of the remaining five plates was done. This procedure was done for each soil sample. The plated were invented and incubated at room temperature for 48 hour to allow for microbial reproduction. Then the colonies were counted for each sample and recorded as colony forming units per ml (cfu/ml) of test material.

3.2.17 Greenhouse Experiment

A greenhouse experiment was set up for the legumes from the two rotations, maize-cowpea and maize-ground rotation. The pots were arranged in a Completely Randomized Design (CRD). Two legumes under investigation were planted together (Cowpea and groundnuts). Pearl millet (*Panicum glaucum L*) Lubasi variety was planted and used as a reference (non N_2 – fixing) crop (Munyinda *et al.,* 2012). Two seeds per pot were planted for each crop and one week after germination thinned to one plant. The plants were allowed to grow for eight weeks. After eight weeks, the plants were uprooted and the number of nodules per plant for the legumes was determined by physically counting and the nodules were stripped from the roots and weighed using a digital weighing balance. The crops were oven dried and tissue nitrogen then determined.

3.2.18 Total Nitrogen in tissue and Biological Nitrogen Fixation

The total nitrogen in plant was determined by the modified Kjeldahl method (Bremner and Mulvaney, 1982). One gram of the oven dried ground material was weighed into a digestion tube to which 10 ml sulphuric acid salicylic acid mixture was added. After 30 minutes, 1.0 gram of sodium thiosulphate ($Na_2S_2O_3.5H_2O$) was added and shaken. The mixture was allowed to stand for 15 minutes thereafter; 10 ml H_2SO_4 acid and one gram catalyst mixture were added. The sample tubes were placed into the digestion block set at 420 ^oC and digested until the samples cleared. Ten milliliters of the digested sample plus 10 ml of KOH were then distilled into 20 ml boric-acid indicator solution. The distillate was titrated with 0.01M HCl and the amount of tissue nitrogen was calculated as indicated below:

$$\text{Total N (\%)} = \frac{\left(\text{volume sample (ml)} - \text{volume blank (ml)}\right) \text{ x normality acid x } 1.4 \text{ x } 10}{\text{mass of sample}} \qquad (8)$$

The amount of N_2 fixed was determined using the Nitrogen Difference Method according to Unkovich *et al.,* (2008). Total N accumulated by N_2-fixing plant and non N_2-fixing plant were compared with the assumptions that; 1) N_2- fixing legumes and non-fixing pearl millet (reference crop) plant use similar amounts of soil mineral N_2, 2) N content of the non N_2 –fixing plant represents the amount of soil mineral N available for plant growth and 3) Total N in the N_2 fixed was calculated as the difference in uptake of N of the N_2 fixing and reference plants multiplied by a factor of 1.5 to account for the below-ground N for the legumes (Unkovich *et al*., 2008). N_2 fixed = (N yield N_2-fixing plant – N yield reference plant) x 1.5. Nodulation was determined by physically counting the number of nodules per plant.

3.2.19 Maize yield

Harvesting of the maize was done after the plants had reached maximum physiological maturity. The maize cobs were harvested from the mid / central rows in each experimental unit excluding all border rows. The maize cobs were harvested and air dried for two weeks and moisture content determine after shelling and the maize yield for each experimental unit was determined using weighing scale.

3.2.20 Statistical Analysis

The results of the measured soil physical, chemical and biological soil parameters were analyzed using analysis of variance (ANOVA) and treatment means separated the LSD test at 95 % confidence level. Statistical analysis was carried out using the SAS package version 9.1.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1.1 Maize - Cowpea rotation

The maize cowpea rotation that was under investigation was 4 years old. Soils from the conservation farming plots and mono-cropped fields for both maize and the legume were sampled and analyzed for the chemical, physical and biological parameters named. The findings are presented below.

4.1.2 Effects of the maize-cowpea rotation on soil chemical parameters

4.1.3 Soil Reaction

The soil pH in the maize-cowpea rotation ranged from pH 5.0 – 5.28. The results indicated non-significant differences in the soil pH among the treatments ($P < 0.05$). Although there were no statistical differences the maize mono-cropping had the highest soil pH as shown in table 3. The cropping sequence had no effect on the soil pH. The low pH from plots with inorganic fertilizer can be attributed to the production of hydrogen protons during the nitrification of nitrogen in fertilizers. Repeated use of ammonium-based N mineral fertilizers presents a potential for soil acidification (Sakala *et al.,* 2000). Acidification will occur in soil with poor buffering capacity to which ammonium sulphate or urea N is applied. If due attention is taken to ensuring that any pH changes are corrected by liming, then such acidification can be avoided (Sakala *et al.,* 2000).

Crop rotation may affect pH through rhizosphere processes and crop residues. Root mediated pH changes in the rhizosphere depends on initial pH, plant species and nutrient constraints to which the plant can respond (Hinsinger *et al.,* 2003). The results showed a consistent trend with the cropping type and agreed with the findings of Hulugalle and Weaver (2005) that a decrease in pH is among the short term changes of soil properties that result from the production of organic acids during the decomposition of crop residues and microbial respiration.

Table 3: Effects of maize-cowpea rotation on soil reaction, nitrogen and carbon

Cropping type	Crop Phase	Soil reaction (pH $CaCl_2$)	Nitrogen (N %)	Organic Carbon (OC %)
Maize-Cowpea rotation + fertilizer	Maize	5.0^a	0.028^b	0.48^a
Maize-cowpea rotation + 0 fertilizer	Maize	5.1^a	0.048^a	0.75^a
Maize mono-cropping + fertilizer	Maize	5.1^a	0.045^a	0.73^a
Maize mono-cropping + 0 fertilizer	Maize	5.28^a	0.050^a	0.72^a
Least Significant Difference (LSD)	Maize	0.29	0.01	0.31
Coefficient of Variation (CV %)		3.69	22	29.7

* Means followed by the same letter within a column are not statistically different at 95% confidence level.

David (2008) also reported soil pH to be affected by application of significant amounts of fertilizer salts which lowers the soil pH. The slightly higher pH values in the maize mono-cropping could be attributed to the steady buildup of organic matter as a result of crop residue retention. The retention of more crop residues in the soil has been associated with an increase in soil organic carbon concentration (Dolan *et al.,* 2006). Furthermore Nyle and Brady (2002) found that soil organic carbon concentration in alkaline soils tend to be low partly because of the effect of a high pH on the chemistry of the soil organic carbon. Soil pH is often hypothesized to be a major factor in regulating organic carbon turnover in agricultural soil.

Mineral fertilizers and organic residues are often not readily available or affordable in sufficient quantities or qualities to be used alone, however integrated soil fertility management (ISFM) currently promotes a management approach that optimizes the use of all available resources within each target environment (Kimani *et al.,* 2003).

4.1.4 Soil organic carbon (SOC) and Total nitrogen

Soil organic carbon results in the maize – cowpea rotation fields are presented in Table 3 and they ranged from 0.48 to 0.75 %. The results indicated non-significant differences among treatments ($P < 0.05$). The results however did not indicate a consistent trend. Relatively higher soil organic carbon was observed in the non-fertilized plots compared to where fertilizer was applied. According to Fairhurst (2012) the critical limit for soil organic carbon is 1.5 %, therefore the soil organic carbon in the maize cowpea rotation field were below optimum level. The rate of accumulation of SOC in the soil is also dependent on the soil texture, climate, vegetation and current land use / management practices (Verhulst *et al.*, 2010).

The relative increase in soil organic carbon in the rotation where fertilizer was not applied, can be attributed to the slower decomposition rate resulting in accumulation of soil organic matter. Earlier studies by Sakala *et al.* (2000) have however shown that under high – input commercial agriculture with large additions of NPK fertilizers, soil organic carbon can increase in the long term. Maintenance of soil organic matter is critical for both soil structure (in most soils) and soil life.

Similarly, analysis of several long-term trials in West Africa also revealed that the organic C contents of plots with fertilizer application are usually comparable to, or slightly higher than the C contents of plots without addition of external inputs (Moore *et al.*, 2000). In the current study, the low soil organic carbon across the treatments / rotation can be attributed to the fact that, crop rotations with little diversity reduce soil carbon by changing the quality and quantity of plant residue input and decomposer diversity (Horwath, 2006).

Seiter and Horwath (2004) observed that crop rotations generally are less effective at increasing soil organic matter in the short term. Similarly Horwath *et al.* (2002) found that a 4-year rotation of maize, tomato, wheat, and sunflower under conventional tillage had a more positive effect on soil carbon than a two-crop rotation. This is attributed to the fact that crop rotations may decrease carbon input to soil, depending on the residue production of selected crops.

Carefully planned rotations containing a variety of crops can maintain or enlarge active soil carbon pools to provide a steady supply of available nutrients for each crop in the rotation (Horwath *et al.*, 2002). However, many growers are often limited by the types of crops that can be grown in rotation because of soil types, climatic limitations, and economics at play. For total nitrogen there were significant differences at ($p \leq 0.05$) among treatments in the maize-cowpea rotation. The results show that the rotation where fertilizer was applied had significantly lower nitrogen level than all the other fields. The nitrogen levels across the fields ranged from 0.028 to 0.05%. The rotation where maize was rotated with cowpea plus fertilizer application was significantly different from the other treatments as shown in Table 3.

The relatively high N % values in the maize-cowpea rotation may be attributed to the high production and accumulation of crop residues in these plots. Similarly the relatively high N % value in the maize mono-crop field can be attributed to the addition and accumulation of crop residues. The maize crop produces larger volumes of residues which do not decompose fast compared to leguminous crop residues. Therefore, the accumulation of maize residues over time could have led to subsequent increase in total nitrogen. Legumes should ideally add more nitrogen to the system.

To the contrally, Umar *et al.* (2011) did not observe any significant differences in plots of five years under conservation farming practice. The authors attributed this effect due to the short period of CF practice. Nitrogen is an essential plant nutrient needed in large amounts and a constituent of amino acids which are required to synthesize proteins and other related compounds.

Therefore, nitrogen plays a role in almost all plant metabolic processes. The nitrogen concentration of soil varies considerably. Most soil contain 0.2 – 0.3 % nitrogen (Peter, 2007). However total nitrogen in the soil cannot be used as a direct interpretation of nitrogen supply to the plants but provides a good indication of soil health. All the levels of nitrogen from the cropping patterns were below the optimal range of 0.2 – 0.3 %. Low total nitrogen in these systems could be due to inconsistencies in the application of the basic principles of conservation farming (CF).

4.1.5 Micronutrients (Zn, Cu, Mn, Fe, S) and Available phosphorus (P)

Table 4: Effects of the Maize-Cowpea rotation on micronutrients (Zn, Cu, Mn, Fe, S) & available phosphorus

Cropping type	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	S (mg/kg)	P (mg/kg)
Maize-cowpea rotation + fertilizer	3.0^{a}	6.8^{a}	219.8^{a}	86.8^{a}	25.9^{a}	12.3^{ab}
Maize-cowpea rotation with no fertilizer	3.0^{a}	5.3^{a}	227^{a}	80.0^{ab}	15.4^{b}	9.8^{ab}
Maize mono-cropping + fertilizer	2.0^{b}	5.0^{a}	186.3^{a}	66.8^{b}	28.2^{a}	18.0^{a}
Maize mono-cropping + no fertilizer	2.8^{a}	6.0^{a}	214.5^{a}	80.3^{ab}	12.7^{b}	8.8^{b}
Least Significant Difference (LSD)	0.74	1.75	73.7	15.3	6.01	8.76
Coefficient of Variation (%)	17.8	19.8	22.6	12.7	19.2	46.7

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

The levels of zinc in the soil ranged from 2 to 3 mg /kg across the fields. While the levels of copper in the soil ranged from 5.3 to 6.8 mg / kg. The highest quantity of copper was recorded from the maize-cowpea rotation where fertilizer was applied, however, results indicated that there were non-significant differences among the treatments ($P < 0.05$).

Manganese levels in the soil ranged from 186.3 to 227 mg/kg. The highest quantity of manganese was recorded from the maize-cowpea rotation without fertilizer application, while the lowest quantity of manganese was from the maize-mono cropping with fertilizer application.

The levels of iron in the soil varied from 66.8 to 86.8 mg/kg. The highest quantity of iron was recorded from the maize-cowpea rotation with fertilizer applied while the lowest quantity was observed from soils from the maize mono cropping with fertilizer application. Sulphur levels ranged from 12.7 to 28.2 mg/kg across the fields. The highest quantity of Sulphur was recorded from the maize mono-cropping where fertilizer was applied and the lowest was from the maize mono-cropping without fertilizer. The trend was that the level of Sulphur was relatively high in cropping sequences where fertilizer was applied compared to where it was not applied.

Phosphorus levels ranged from 8.8 to 18 mg/kg. The highest level was recorded from the maize mono cropping with fertilizer application, while the lowest was recorded from the maize mono-cropping without fertilizer. Relatively high values were observed from the maize-cowpea rotation where fertilizer was applied and where no fertilizer was applied. The results indicated that there were significant differences among the cropping sequences. The maize mono-cropping with fertilizer and without fertilizer were statistically different from each other. These differences can be attributed to the availability of residual fertilizer, in the fertilized plots. On the other hand in the non-fertilized maize mono-cropped plots this could be due to low availability of phosphorus. The trend of availability of phosphorus was higher in the cropping sequences where fertilizer was applied compared to where it was not applied. The observed differences could therefore be attributed to the residual P in the inorganic fertilizers that have been applied over time.

In Zambia D-compound fertilizer sold on the market contains 20 % P_2O. The optimum phosphorus availability according to Brady (1990) is when soil reaction (pH) range is between 6 and 7. The pH in the current study ranged from 5.0 to 5.28, indicating that there was no tangible relationship with P levels in the soil. Similarly Behera *et al.* 2008 noted that productive soils generally have a pH of between 5 and 8 (measured in calcium chloride). Most agricultural soils many of which are acidic are also phosphorus deficient or quickly become deficient in the absence of added phosphorus from fertilizers under cropping.

The quantity of zinc in the maize mono-cropping with fertilizer was lower compared to the other cropping patterns. The general trend in both cropping sequences was that the availability of Zn was low in plots where the pH was low. According to Peter (2007), the critical limit of zinc in soils lies between 15 – 20 mg kg^{-1}. All the results in the study

were below the critical limit regardless of the cropping type. Maize is classified as being very sensitive to Zinc deficiency, meaning that maize has a high requirement for zinc.
The availability of zinc tend to vary due to either; intensive conventional farming, growing of high yielding varieties, application of high analysis NPK fertilizers against non-use of zinc fertilizers and reduced or non-use of organic manures (Behera *et al.*, 2008). The increase in zinc availability in plots where crop rotation was being practiced can be attributed to crop residue retention which resulted in high accumulation of organic matter in the soil. Mengel and Kirkby (2001) showed that excess P quantities affected the physiological zinc availability of plants.

The level of (Fe) iron among the treatments varied. The differences in the level iron may be attributed to the variations in the cropping type and soil pH. Iron is an important micronutrient present in several peroxidase, catalase, and cytochrome oxidase enzymes found in ferredoxin, which participates in oxidation-reduction reactions (Tisdale *et al.*, 1985).
For sulphur the results indicated that there were significant differences among the treatments ($P < 0.05$). The low levels of sulphur in the cropping sequence where fertilizer was not applied can be attributed to the fact that legumes and most crops have a high requirement of this elements attributed to the vital role it plays in plant growth. These observed differences can be attributed to the residual Sulphur in the fertilizer that have been applied over time. Most of the D-compound fertilizer found on the market contain about 6 to 8 % Sulphur (Peter, 2007). In Zambia the threshold for sulphur and phosphorous is between 10 to 12 mg/kg. The global mean concentration of sulphur in soils is 433 mg kg^{-1} (Peter, 2007) For Zambian soils, Tsuji *et al.* (2005) reported relatively low levels between 110 to 150 mg kg^{-1} in a study done to assess the distribution of total sulphur in major Zambian soils. Brady (2002) observed that intensive cropping in which large amounts of plant nutrients are removed in the harvest, accelerated the depletion of micronutrients reserves in the soil and increased the likelihood of micronutrient deficiencies. Micronutrients are taken up by plants in relatively small amount and hence, the name trace elements or micronutrients (Mengel & Kirkby, 2001).

4.1.6 Exchangeable bases (K^+, Na^+, Ca^{++}, Mg^{++})

Table 5 presents the results of exchangeable bases as influence by the maize-cowpea rotation. The bases ranged as follows; calcium 4.0 to 4.59 cmol/kg, while magnesium 2.81 to 3 cmol/kg, with potassium 0.26 to 0.47 cmol/kg and sodium 0.06 to 0.07 cmol/kg.

Table 5: Effects of the maize-cowpea rotation on the exchangeable bases

Cropping type	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)
Maize-cowpea rotation + fertilizer	4.59[a]	3.00[a]	0.41[ab]	0.065[a]
Maize-cowpea rotation with no fertilizer	4.31[a]	2.94[a]	0.47[a]	0.065[a]
Maize mono-cropping + fertilizer	4.00[a]	2.81[a]	0.26[b]	0.068[a]
Maize mono-cropping + no fertilizer	4.00[a]	2.88[a]	0.33[ab]	0.060[a]
Least Significant Difference (LSD)	0.9732	0.7095	0.1595	0.0277
Coefficient of Variation (CV %)	14.9	15.8	28.2	27.9

X* means followed by the same letter within a column are not statistically different at 95% confidence level

The general trend in all the cropping sequences was that the available levels of the bases was relatively higher in crop rotations treatments than mono-cropping. This is both where fertilizer was applied and not applied as compared to relatively low levels in maize-mono cropped fields. These results when compared with the baseline soil analysis results obtained four years ago indicated that calcium and magnesium are lower than the initial levels.

Meanwhile the available levels of potassium and sodium were slightly higher than at the start of the study. Though sodium is not required for plant growth, increased amounts of this element may affect the soil structure dispersion.

Statistically the maize-cowpea rotation had non-significant effect at $p < 0.05$ on calcium, magnesium and sodium. The cropping sequence, however did have a significant effect at $p < 0.05$ on the level of potassium. The increase in the level of potassium in the cropping sequences where maize was rotated with cowpea both with and without fertilizer application is in agreement with the findings of Govaerts *et al.*, (2008). He reported significant higher amounts of exchangeable bases in CF fields as compared to conventional fields. This can be attributed to crop residue retention which led to a gradual buildup of organic matter in the soil over time. Similarly Bationo *et al.* (2007) also reported that mono-cropping and lack of restitution of crop residues contributes to increase in soil acidification leading to significant decrease in soil exchangeable bases.

4.1.7 Cation Exchange Capacity (CEC)

Figure 1 presents the results of the cation exchange capacity (CEC) as influenced by the maize-cowpea rotation. The CEC values ranged from 7.28 – 8.05 meq / 100g of soil. These CEC values were within the critical limits of 5 – 30 meq / 100g of soil which is the range for most soils that are used for crop production (Nyle and Brady, 2002). The highest value was observed from the maize cowpea rotation where no fertilizer was applied and the lowest value was observed from the maize mono-cropping field.

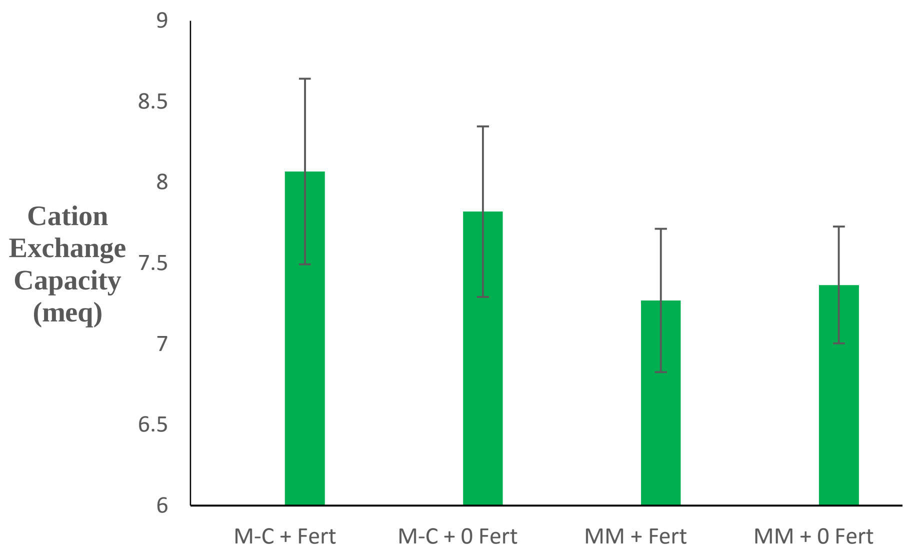

Figure 1: Cation Exchange Capacity in soils under maize-cowpea rotation and mono-cropping

The results on CEC indicated that crop rotation had no significant effect on the CEC and this can be attributed to the role of organic matter which was not different across the rotation and mono-crop fields. The CEC levels across the fields were generally low due to low SOC and pH levels. The variations in the CEC can be attributed to the amount of organic matter in the soil. Mclean *et al.* (1983) observed that soils with enough well decomposed organic matter will have a high CEC value than soils that are sandy. However if the soil has a small percentage for instance 1% organic matter its contribution to the CEC is insignificant.

4.2.0 Effects of crop rotations on soil physical properties

4.2.1 Bulk density and Total porosity

Table 6 shows the maize cowpea rotation with the bulk densities ranging from 1.32 to 1.39 g/cm^3 and that the results were non-significant different ($p < 0.05$). Total porosity ranged from 47.5 to 49.8 % and was not-significant different ($p < 0.05$) among the cropping types as shown in Table 6. The lack of differences in bulk densities among the soils is in agreement with the findings of Verhulst *et al.* (2010) who under minimum and conventional tillage in a short-term experiments of less than 10 years found that there were no clear effects of management practices on bulk density. The reason why the porosity and bulk density value were not significantly different can be attributed to the fact that minimum soil disturbance under conservation farming reduces bulk density due to organic matter build up.

Table 6: Effects of the Maize-Cowpea rotation on bulk density & total porosity, infiltration rate and plant available water

Cropping type	Bulk density (g/cm^3)	Total Porosity (%)	Infiltration Rate (cm/min)	Plant Available Water (v/v) cm^3/cm^3
Maize-cowpea rotation + fertilizer	1.32^{a}	49.0^{a}	0.15^{a}	0.23^{ab}
Maize-cowpea rotation with 0 fertilizer	1.39^{a}	47.5^{a}	0.16^{a}	0.25^{a}
Maize mono-cropping + fertilizer	1.37^{a}	48.1^{a}	0.18^{a}	0.24^{ab}
Maize mono-cropping + no fertilizer	1.33^{a}	49.8^{a}	0.20^{a}	0.18^{b}
Least Significant Difference (LSD)	0.1261	4.77	0.1566	0.0618
Coefficient of Variation (CV %)	6.0	6.37	59.8	17.9

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

The bulk densities recorded from the current study were below 1.45g/cm^3, indicating that plant root penetration cannot be affected. Apart from promoting a good plant root relationship, lower bulk densities may promote aeration and water movements which ultimately enhance crop productivity (Rasaily, 2012). Higher bulk density imply that the soils are compacted and generally compacted soils reduces that amount of water that plants can take up.

Total porosity (proportion of pores) is normally calculated bulk density, which is another factor that determines the physical conditions of the soil and influences aeration, water movement and root penetration (Nyle and Brady, 2002).

4.2.2 Infiltration Rates and Plant Available Water

The infiltration rates results from the maize cowpea rotation ranged from 0.15 to 0.20 cm/min (Table 6). The infiltration rates among the treatments were non-significant ($p < 0.05$). The plant available water results ranged from 0.18 to 0.25 (v/v) cm, and there were significant differences among the cropping types ($p < 0.05$). The maize mono-cropping with no fertilizer had the lowest plant available water and it was significantly different from the maize-cowpea rotation with no fertilizer which had the highest value among the four cropping types. The low plant available water in the maize mono-cropping without fertilizer can be attributed to reduced crop residue on the soil surface and hence low organic matter in the soil.

To support these findings Ball *et al.* (1997) reported that retaining crop residues under conservation farming reduces evapo-transpiration and increases infiltration rates and available water. Similarly Christian and Patrick (2009) reported higher infiltration and soil moisture in conservation farming plots with residue retention. The bulk density values also recorded in this current study were within the optimal range not to negatively affect the infiltration rates and plant available water. Normally increases in bulk density result in large decreases in water flow through the soil (Nyle and Ray, 2002). Additionally the amount of soil water available for plant uptake is determined by a number of factors including water content-potential relationship for each soil horizon, soil depth and soil stratification (Peter *et al.,* 2007). The results from this study shows that returning crop residues improves the plant available water in the soil. Henceforth crop residue retention should be encouraged.

4.3.0 Effects of crop rotations on soil biological properties

4.3.1 Soil Microbial Biomass – C

Soil microbial biomass in the maize cowpea rotation ranged from 0.19 to 0.45 mg/g of soil. The highest microbial biomass was recorded from the maize mono cropping where no fertilizer was applied (figure 2). The lowest microbial biomass was observed in the maize-cowpea rotations than those in the maize mono-cropping soils. These results showed significant differences ($p < 0.05$) among the cropping patterns. The cropping patterns had significant effect on the microbial biomass.

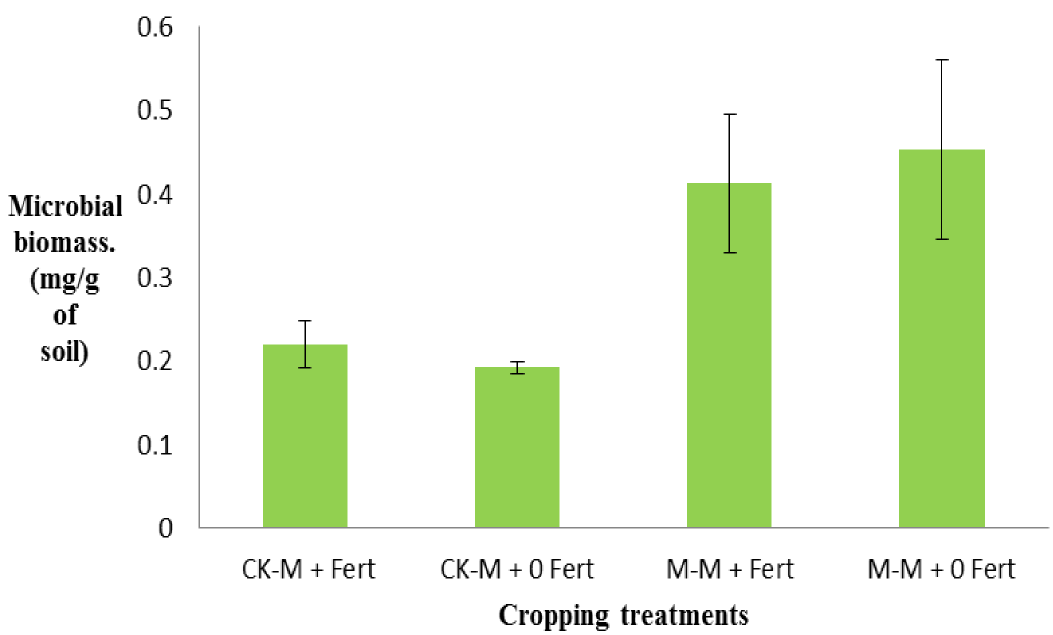

Figure 2: Soil microbial biomass under maize-cowpea rotation and maize mono-cropping

These results are contrary to the findings of Alvear *et al.* (2005) who reported higher microbial biomass under conservation faming than in conventional tillage. However the results of the current study could be attributed to organic matter buildup over time leading to increased microbial population. Buchanan and King (1992) reported increases in soil microbial biomass in monoculture of maize with residue retention in zero tillage compared to conventional tillage.

Soil organic matter is a substrate for soil microorganisms. This can also be attributed to the fact that, the maize plants produce more biomass than cowpeas. It is well known that soil organic C strongly affects the amount and activity of soil microbial biomass (Jenkinson, 1988). On the other hand the maize cowpea rotation treatments had lower microbial biomass that could be attributed to the rotating of two different crops in the same field and the possibility of different root exudates which may affect microbial biomass. Marshner *et al.* (2001) found that the rhizospheric microbial community was plant species specific, and reported that the root exudates are different from different plants. The author emphasized that even different cultivars of the same plants differed in root exudates thus causing differences in the rhizosphere communities associated with the plants. Therefore, it is expected that the microbial biomass under maize mono-cropping and maize in rotation with cowpea would differ significantly.

4.3.3 Cowpea nodulation

Table 5 presents that the number of nodules per cowpea plant and weights. The number of nodules ranged from 31 – 58 per plant. There was a significant difference in the number of nodules in the various cropping systems. In this rotation more nodules per plant were recorded from soils where maize was rotated with cowpea and no fertilizer was applied. And lower numbers of nodules per plant were observed in treatments where fertilizer was applied (Table 7).

Table 7: Effects of the maize-cowpea rotation on nodulation

Cropping type	Number of nodules per plant	Weight of nodules (g / plant)
Maize-cowpea rotation + fertilizer	31[b]	0.80[a]
Maize-cowpea rotation with no fertilizer	58[a]	0.62[a]
Least Significant Difference (LSD)	13.0	0.61
Coefficient of Variation (CV %)	16.9	50

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

In terms of nodule weight, the results were not different as compared to the number of nodules per plant. Nodule weight from all the treatments were not significantly affected by fertilization. The reduced number of nodules from soils where fertilizer was applied can be attributed to the negative effect of nitrogen fertilizer on nodule initiation and development (Mweetwa *et al.,* 2016). These findings are consistent with Amba *et al.* (2013) who found the application of nitrogen fertilizer to reduce the number of nodules, while the application of phosphorus fertilizer produced higher number of nodules. Similarly Carr *et al.* (2000) reported that application of nitrogenous fertilizer significantly produced lesser number of nodules and they concluded that any dose of applied nitrogenous fertilizer inhibited nodule formation. The inhibitory effects of added nitrogen fertilizer to nodulation has been attributed to the inhibition of early cell division in the cortex and infection threads thereby inhibiting nodulation (Gentili *et al.,* 2006).

4.3.4 Biological Nitrogen Fixation

Table 8 shows the effects of maize-cowpea rotation on biological nitrogen fixation in terms of N % fixed and maize yield. The biological nitrogen fixation (N % fixed) ranged from 0.63 to 1.12 N %. The results indicated non-significant differences at $p > 0.05$ among the treatments. The highest nitrogen fixed was recorded from the maize-cowpea rotation without fertilizer application. The lowest nitrogen fixed was observed in the maize-cowpea rotation and the mono crop where fertilizer was applied. However, there were no statistical differences among the treatments. The low levels of nitrogen fixed could be attributed to the negative effects of nitrogenous fertilizer on the process of biologically fixed nitrogen. Also the low levels of N % fixed could be related to the low soil organic carbon in the soil.

Table 8: Effects of the maize-cowpea rotation on the N % fixed and maize yield.

Cropping type	BNF (N % fixed)
Maize-cowpea rotation + fertilizer	063[a]
Maize-cowpea rotation + 0 fertilizer	1.12[a]
Maize mono-cropping + fertilizer	0.63[a]
Maize mono- cropping + 0 fertilizer	1.12[a]
Least Significant Difference (LSD)	0.7475
Coefficient of Variation (CV %)	111.1

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

Muchabi *et al.* (2014) reported that improved soil properties such as increased soil porosity, higher soil organic carbon content, increased pH and increased chemical fertility to contribute to increased nitrogen fixation in legumes. The amount and form of nitrogen applied per unit area as fertilizer, are all important. Urea, NH_4^+, NH_3 and NO_3- are the most commonly used sources of fertilizer nitrogen.

Both nitrate and ammonium-N sources have been found to inhibit nitrogen fixation when urea is applied (Tisdale *et al.,* 1985). The superiority of urea is still not clear because in the soil conditions urea is converted to nitrate. However some studies have shown evidence of the inhibitory effects of nitrates on nodulation in legumes. Bottomley and Myrold (2007) stated that the process of reducing atmospheric nitrogen requires a large input of energy to proceed as 16 moles of adenosine triphosphate (ATP) is required to reduce 1 mole of nitrogen. Higher organic C content serves as a source of energy which is needed in the reduction of atmospheric nitrogen.

The health and vigor of the host plant also plays an important role in the rhizobium-legume relationship. The lack of a positive relationship between nodulation and the amount of nitrogen fixed may be an indication that rotating two crops in the same field reduces the population of indigenous strains, of rhizobium bacteria which may result in them not being effective at fixing nitrogen. Nodulation competiveness as defined by Castro *et al.* (1999) is the ability of a given strain to dominate nodulation in the presence of other strains of the same species.

4.3.5 Maize yield

Figure 3 presents results on maize yield. The maize yield ranged from 0.93 to 2.81 tonnes per hectare. The maize yields were higher in plots where fertilizer was applied as compared to plots where no fertilizer was applied. There were significant differences among the cropping types ($p < 0.05$).

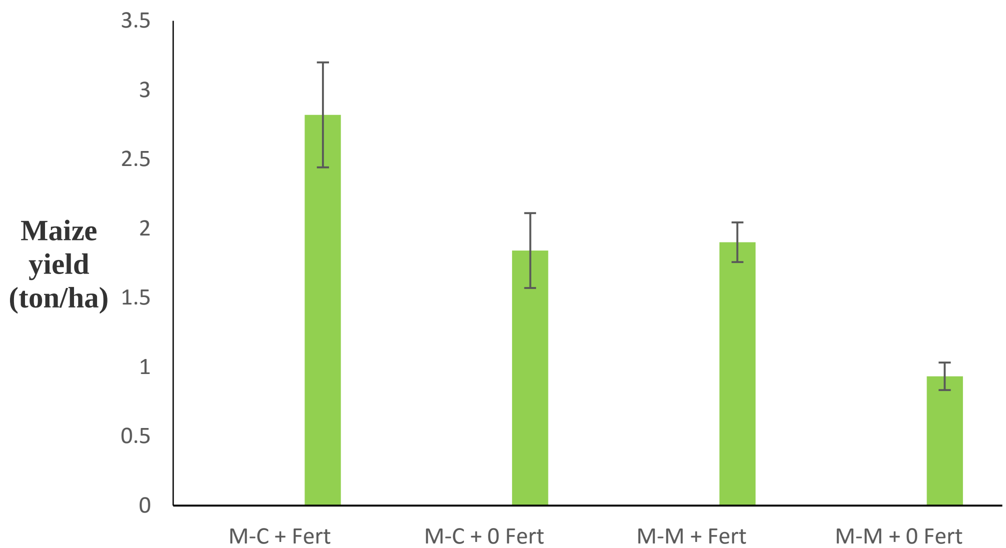

Figure 3: Maize yields from the maize-cowpea rotation and maize mono cropping soils

The maize cowpea rotation with fertilizer had the highest yield as compared to the treatments where the maize and cowpea were rotated without fertilizer. These results are in agreement with the findings of Vanlauwe and Giller (2006) who reported that the combined use of inorganic and organic fertilizer to improves the fertilizer use efficiency by plants and subsequently improves crop yields.

The use of inorganic fertilizer improves crop yields and thus increases the amount of organic matter returned to the soil through roots and potentially through crop residues (Gupta, 2011). A non-decreasing trend in maize yield is necessary for a system to be called sustainable. This study showed that inorganic fertilizer application resulted in no significant effect in the maize cowpea rotation.

The stability of yield is an important characteristic to be considered when judging the value of a cropping system. The yield results in this crop rotation are in agreement with the findings of Zhang *et al.* (2000) who reported lower maize yields in mono-cropping plots than in a long term rotational experiment, which was conducted in China. The yield increase in the fertilizer treated plots confirms that crop residues (organic manure) with NPK supplementation are efficient ways of fertilization.

However, Karlen *et al.* (1994) also reported that no amount of chemical fertilizer alone can fully compensate for crop rotation effects. It can be suggested that the joint application of crop residues (organic fertilizer) arising from crop residue retention and mineral fertilizer may provide more favourable conditions for the manifestation of the rotation effect.

The retention of crop residues represents not only the additions of inorganic nutrients but also as an ecological method of sustaining soil productivity. Long term use of crop rotation or addition of crop residues may increase soil aggregation stability, microbial and earth worm activity and soil water storage and optimize the soil physical environment for crop growth.

4.4.0 Maize-Groundnut Rotation

The maize-groundnut rotation was 10 years old and the soils were sampled from the conservation farming plots where a cereal and legume have been crop rotated after every season and from the mono-cropped plots.

4.4.1 Effects of the Maize-Groundnut Rotation on the soil chemical properties

4.4.2 Soil Reaction

Table 9 present the soil reaction (pH) which ranged from 4.7 to 5.3. These results showed that there was no significant difference between the cropping sequences at ($p < 0.05$). The highest soil pH was in the maize phase and the lowest in the groundnut phases. The high soil reaction (pH) recorded from the maize mono-cropping plots can be attributed to the high accumulation of crop residues and subsequently leading to increased organic matter which may have improved the soil reaction over time.

Meanwhile the low pH recorded from the cereal /legume rotation in soils agrees with the findings of Helyar and Porter (1989) which indicates that the presence of legumes in agricultural system influences soil acidity, through the N and C cycles. Legumes increase soil organic N through N fixation and subsequent oxidation of organic N followed by $N0_3$ leaching is the main acidifying process (Helyar, 1976). Secondly the excretion of the H^+ from legume roots due to the uptake of more cations than anions, is another reason for accelerated acidification associated with legume growth (Haynes, 1983).

4.4.3 Soil Organic Carbon and Nitrogen

Table 9 presents results for soil reaction, nitrogen and organic carbon as influenced by the maize and groundnut rotation. Soil organic carbon results ranged from 0.22 to 0.67 and the results indicated that there were significant differences among the cropping patterns ($p < 0.05$).

Table 9: Effects of the maize-groundnut rotation, mono-cropping and fertilization on soil reaction, nitrogen and organic carbon.

Cropping Type	Crop Phase	Soil Reaction pH (CaCl2)	Nitrogen (N %)	Organic Carbon (%)
Maize-Groundnut rotation + 0 fertilizer	Maize	5.2[a]	0.03[a]	0.58[ab]
Maize-Groundnut rotation + fertilizer	Maize	5.1[a]	0.03[a]	0.54[ab]
Maize mono cropping + 0 fertilizer	Maize	5.3[a]	0.04[a]	0.67[a]
Maize mono cropping + fertilizer	Maize	5.2[a]	0.02[a]	0.35[ab]
Maize groundnut + 0 fertilizer	Groundnut	4.9[a]	0.02[a]	0.30[b]
Maize-Groundnut rotation + fertilizer	Groundnut	4.7[a]	0.02[a]	0.22[b]
Groundnut mono cropping + 0 fertilizer	Groundnut	5.0[a]	0.03[a]	0.35[ab]
Groundnut mono-cropping + fertilizer	Groundnut	5.0[a]	0.02[a]	0.42[ab]
Least Significant Difference (LSD)		0.61	0.02	0.36
Coefficient of Variation (CV %)		6.6	45.7	49.3

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

The critical limit of soil organic carbon in most soils is 1.5% (Fairhurst, 2012). All the values recorded from this rotation were below the critical limit. The highest SOC value was recorded from the maize mono-cropping soils where no fertilizer was applied. Meanwhile, the lowest SOC was recorded from the maize groundnut rotation where fertilizer was applied. The SOC was not significantly different under both maize groundnut rotation comprising of both fertilized and unfertilized conditions.

The variations in the levels of soil organic carbon could be attributed to the effect of the application of fertilizer on the rate of decomposition of organic matter. When nitrogen is applied to a system the rate of organic matter decomposition is accelerated. An increase in the SOC from some soils in this cropping system can be attributed to increased organic matter accumulation as a result of reduced rate of organic matter decomposition of crop residues mostly in soils where fertilizer was not applied.

Additionally the low soil organic carbon can be linked to the fact that crop rotations with little biomass production and diversity reduce soil carbon by changing the quality and quantity of plant residues (Horwath, 2006). Results on soil nitrogen ranged from 0.02 to 0.04 % and there were no significant differences among the cropping patterns (Table 9). The highest nitrogen level was recorded from the maize- mono-cropping where no fertilizer was applied. Most soils contain 0.2 to 0.3 % nitrogen (Peter, 2007) and all the results were below this critical limit.

4.4.4 Micronutrients (Zn, Cu, Mn, Fe, S) and Available phosphorus (P)

Table 10: Effects of the maize-groundnut rotation and mono-cropping on micronutrients (Zn, Cu, Fe, S, Mn) and available phosphorus

Cropping type	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	S (mg/kg)	P (mg/kg)
Maize-G/nut rotation+0 fert-MP	2.00^{b}	12.0^{ab}	476.7^{a}	123.3^{ab}	16.7^{dc}	2.0^{b}
Maize-G/nut rotation + fert-MP	2.40^{b}	10.0^{b}	410.0^{a}	118.2^{ab}	28.8^{abcd}	4.0^{b}
Maize mono-cropping + 0 fert-MP	2.33^{b}	13.3^{a}	447.0^{a}	103.4^{b}	14.2^{d}	2.0^{b}
Maize mono-cropping + fert-MP	3.33^{a}	12.3^{ab}	467.3^{a}	148.6^{a}	42.3^{a}	17.7^{ab}
Maize-G/nut rotation + 0 fert-GP	2.33^{b}	13.0^{a}	480.7^{a}	138.2^{ab}	19.3^{bcd}	1.7^{b}
Maize-G/nut rotation + fert-GP	2.33^{b}	12.3^{ab}	454.7^{a}	130.0^{ab}	35.4^{abc}	6.0^{b}
G/nut mono-cropping + 0 fert-GP	1.67^{b}	11.7^{ab}	412.0^{a}	113.0^{ab}	24^{abcd}	2.0^{b}
G/nut mono-cropping + fert-GP	4.00^{a}	13.3^{a}	428.0^{a}	133.9^{ab}	38.5^{ab}	23.0^{a}
Least Significant Difference	0.896	2.5722	125.6	37.9	19.3	16.7
Coefficient of Variation (CV %)	32	13.1	15	18.4	48.1	149.6

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

The levels of zinc in the soil ranged from 1.67 to 4 mg/kg across the fields. A relatively high level of zinc was observed from the groundnut mono-cropping where fertilizer was applied. A low level of zinc was observed from the groundnut mono-cropping fields where no fertilizer was applied. The results showed that the levels of zinc varied among the cropping patterns. The zinc levels were significantly different ($P<0.05$). The maize mono-cropping with fertilizer and the groundnut mono-cropping with fertilizer were not different from each other. According to Peter (2007) the zinc critical limit in soils ranges from 15 – 20 mg kg^{-1}. And all the results obtained in all the treatments were below this critical limit. Maize is classified as being very sensitive to Zinc deficiency. Maize has a high requirement for zinc. The results also indicated that the level of zinc in all the treatments was inversely proportional to the level of available phosphorus in the soil. Studies have shown that the availability of zinc is affected by a number of factors. Intensive farming, growing of high yielding varieties, application of high analysis NPK fertilizers against non-use of zinc fertilizers and reduced or non-use of organic manures reduces zinc levels (Behera *et al.*, 2008). The increase in zinc availability in plots where crop rotation was being practiced can be attributed to crop residue retention which led to organic matter in the soil over time.

The levels of copper in the soil ranged from 10 to 13.3 mg / kg. The highest quantity of copper was recorded from the groundnut mono-cropping with fertilizer and from the maize-mono-cropping without fertilizer. These results indicated that there were significant differences among the treatments ($P \leq 0.05$). The organic matter, organic residues, and manure applications affect the immediate and potential availability of micronutrients such as copper (Peter, 2007).

Manganese levels in the soil ranged from 410 to 480.7 mg/kg. The highest level of manganese was recorded from the maize-groundnut rotation without fertilizer application, while the lowest level of manganese was from the maize-groundnut rotation with fertilizer application. These results indicated that they were non-significant differences among the treatments ($P < 0.05$). Manganese is essential for nitrogen transformations in micro-organisms as well as plants.

The levels of iron (Fe) in the soil ranged from 103.4 to 148.6 mg/kg. The highest level of iron was recorded from the maize-mono-cropping with fertilizer application while a low level was observed from soils from the maize mono cropping without fertilizer application. The critical level of iron based on Mehlich III extractant is 4.8 mg/kg (Halvin and Soltanpour, 1981).

Sulphur (S) levels ranged from 14.2 to 42.2 mg/kg across the fields. The highest level of Sulphur was recorded from the maize- mono-cropping where fertilizer was applied while the lowest S was from the maize mono-cropping without fertilizer. The trend was that the level of sulphur was relatively high in cropping sequences where fertilizer was applied compared to where it was not applied. The results indicated that there were significant differences among the treatments ($P < 0.05$). The low levels of Sulphur in the rotation where fertilizer was not applied can be attributed to the fact that legumes and most crops have a high requirement of this element as it plays a vital role in plant growth.

Similarly these observed differences can be attributed to the residual sulphur in the fertilizer that have been applied over time. In the soil, sulphur occurs in organic and inorganic forms and is cycled within and between these forms via mobilization, immobilization, mineralization, oxidation and reduction processes (Pamela, 1998). Mclaren *et al.* (1985) reported that organic compounds are largely immobile, while inorganic compounds are more mobile. D-compound fertilizer contains about 6 to 8 % per 50kg bag of Sulphur (Peter, 2007). In Zambia the threshold for Sulphur and phosphorous is between 10 to 12 mg/kg. However Tsuji *et al.* (2005) reported relatively low levels between 110 to 150 mg kg^{-1} in the major Zambian soils.

Phosphorus levels ranged from 1.7 to 23 mg/kg. The highest level was recorded from the maize mono cropping with fertilizer application, while the lowest was recorded from the groundnut mono-cropping without fertilizer. The results showed that they were significant differences among the treatments ($P > 0.05$). The trend was that availability of phosphorus in soils was higher in the cropping sequences where fertilizer was applied compared to where it was not applied. The observed differences could therefore be attributed to the residual P in the fertilizers that have been applied over time. D-compound fertilizer contains 20% P_2O (Peter, 2007).

The maximum phosphorus availability according to Brady (1990) is when soil reaction (pH) range is between 6 and 7. The pH in the current study ranged from 5.0 to 5.28. This indicates that there was no tangible relationship with P levels in the soil. Mengel and Kirkby (2001) showed that excess P quantities affected the physiological zinc availability of plants. Brady (2002) also observed that intensive cropping in which large amounts of plant nutrients are removed in the harvest accelerated the depletion of micronutrients reserves in the soil and increased the likelihood of micronutrient deficiencies.

4.4.5 Exchangeable bases (K^{+}, Na^{+}, Ca^{++}, Mg^{++})

Table 11 presents results the results of the exchangeable bases as influenced by the maize-groundnut rotation and mono-cropping. The bases ranged as follows calcium (3.9 to 7.4) cmol/kg, potassium (0.1 to 0.27) cmol/kg, sodium (0.12 to 0.23) cmol/kg and magnesium (3.19 to 4.69) cmol/kg.

Table 11: Effect of the maize-groundnut rotation on exchangeable bases

Cropping type	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)
Maize-G/nut rotation + No fertilizer-MP	5.85[a]	4.47[a]	0.13[ab]	0.16[a]
Maize-G/nut rotation + Fertilizer-MP	5.60[a]	4.50[a]	0.14[ab]	0.09[a]
Maize mono-cropping + 0 Fertilizer-MP	6.45[a]	4.69[a]	0.14[ab]	0.18[a]
Maize mono-cropping + Fertilizer-MP	6.70[a]	4.58[a]	0.18[ab]	0.16[a]
Maize-G/nut rotation + NO Fertilizer-GP	3.90[a]	3.19[a]	0.10[ab]	0.12[a]
Maize-G/nut rotation + Fertilizer-GP	5.92[a]	4.45[a]	0.16[ab]	0.23[a]
G/nut mono-cropping + NO fertilizer-GP	5.03[a]	3.95[a]	0.10[b]	0.12[a]
G/nut mono-cropping + Fertilizer-GP	7.40[a]	4.67[a]	0.27[a]	0.13[a]
Least Significant Difference (LSD)	3.8762	2.105	0.167	0.1524
Coefficient of Variation (CV %)	37.1	26.6	62.6	59.2

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

Calcium levels indicated that there were no significant differences ($p > 0.05$) among the cropping patterns. The levels of calcium was within the critical range of 5 – 10 cmol/kg, except for the soils from the maize groundnut rotation. Similarly magnesium levels indicated that they were non-significant differences among the cropping types and the values were within and above the critical limit in soil of 1.5 to 3.0 cmol/kg.

The results for potassium indicated that there were significant differences among the cropping types. These results were below the critical limit range of 0.3 to 0.6 cmol/kg (Table 11). The groundnut mono cropping without fertilizer was different from the results from the groundnut mono cropping with fertilizer.

The groundnut mono cropping and the maize – groundnut rotation both without fertilizer had the lowest potassium level. The low levels of potassium recorded can be attributed to the fact that maize and groundnuts have a high requirement for the element K. The results of the major bases calcium, magnesium and potassium when compared with the initial results in table 8b, show that availability of the bases decreased over this period.

4.4.6 Cation Exchange Capacity (CEC)

The CEC ranged from 7.4 to 12.0 meq per 100g of soil. These results indicated that crop rotation had no significant effect on the CEC capacity (Table 12). The CEC values were within the range of 5 to 30 meq/100g of soil and most of the soils used for crop production fall within this range (Peter, 2007). Soils with a low CEC (i.e. sandy soils) indicate that the soil are low in organic matter and have low buffering capacities (Brady, 2011).

Table 12: Effect of the maize-groundnut rotation on cation exchange capacity (CEC)

Cropping type	CEC (meq/100g soil)
Maize-G/nut rotation + No fertilizer-MP	10.3^a
Maize-G/nut rotation + Fertilizer-MP	9.9^a
Maize mono-cropping + NO Fertilizer-MP	11.1^a
Maize mono-cropping + Fertilizer-MP	11.3^a
Maize-G/nut rotation + NO Fertilizer-GP	7.4^a
Maize-G/nut rotation + Fertilizer-GP	10.3^a
G/nut mono-cropping + NO fertilizer-GP	9.1^a
G/nut mono-cropping + Fertilizer-GP	11.9^a
Least Significant Difference (LSD)	5.48
Coefficient of Variation (CV %)	31.1

X* means followed by the same letter within a column are not statistically different at 95% confidence level. Mp = Maize plot, Gp = Groundnut plot

4.5.0 Effects of the Maize-Groundnut Rotation on soil physical Properties

4.5.1 Bulk density and Total Porosity

Table 13 shows the effect of maize-groundnut rotation and mono-cropping on bulk density. Bulk density ranged from 1.19 to 1.33 g/cm^3. The results were not significantly different ($p < 0.05$). Total porosity varied from 49.7 to 54.4% and was non-significant different ($p < 0.05$) among cropping types.

The lack of differences in bulk densities and porosities among the soils is in agreement with the findings of Verhulst *et al.* (2010) who under minimum and conventional tillage in a short term experiment of less than 10years found that there were no clear effects of management practices on bulk density and porosity.

Table 13: Effect of the maize-groundnut rotation on bulk density and total porosity

Cropping type	Bulk Density (g/cm^3)	Total Porosity (%)
Maize-G/nut rotation + No fertilizer-MP	1.24^a	53.2^a
Maize-G/nut rotation + Fertilizer-MP	1.27^a	52.3^a
Maize mono-cropping + NO Fertilizer-MP	1.26^a	52.3^a
Maize mono-cropping + Fertilizer-MP	1.33^a	49.7^a
Maize-G/nut rotation + NO Fertilizer-GP	1.21^a	54.4^a
Maize-G/nut rotation + Fertilizer-GP	1.28^a	51.7^a
G/nut mono-cropping + NO fertilizer-GP	1.32^a	50.3^a
G/nut mono-cropping + Fertilizer-GP	1.19^a	55.3^a
Least Significant Difference (LSD)	0.1862	6.9718
Coefficient of Variation (CV %)	8.5	7.7

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

The bulk density observed from the current study were below 1.45 g/cm^3, indicating that challenges of plant root penetration may not be encountered. Apart from promoting a good plant root relationship, low bulk density does promote aeration and water movements which ultimately enhance crop productivity. Higher bulk density imply that the soils are compacted, however this is not always the case in some soil. Generally compacted soils reduces the amount of water that plants can take up. The creation of more very fine micropores increases the permanent wilting coefficient and so decrease the available water content (Nyle and Brady, 2002).

4.5.3 Infiltration rates and plant available water

The infiltration rates from the maize groundnut rotation ranged from 0.01 to 0.24 cm/min (Table 14). The results indicated that there was non-significant difference ($P < 0.05$) among the cropping patterns. The plant available water ranged from 0.14 to 0.29 (v/v). The highest plant available water was from maize-groundnut rotation with fertilizer application while the lowest was from the maize-groundnut rotation without fertilizer application and from the groundnut mono-cropping with fertilizer application.

Table 14: Effect of the maize-groundnut rotation on infiltration rate and plant available water

Cropping type	Infiltration Rate (cm/min)	Plant Available Water (v/v) cm^3/cm^3
Maize-G/nut rotation + No fertilizer-MP	0.24^a	0.18^b
Maize-G/nut rotation + Fertilizer-MP	0.12^a	0.29^a
Maize mono-cropping + NO Fertilizer-MP	0.30^a	0.19^b
Maize mono-cropping + Fertilizer-MP	0.14^a	0.16^b
Maize-G/nut rotation + NO Fertilizer-GP	0.13^a	0.14^b
Maize-G/nut rotation + Fertilizer-GP	0.09^a	0.28^a
G/nut mono-cropping + NO fertilizer-GP	0.10^a	0.28^a
G/nut mono-cropping + Fertilizer-GP	0.23^a	0.14^b
Least Significant Difference (LSD)	0.25	0.05
Coefficient of Variation (CV %)	84.4	14.7

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

The relatively high values observed for the plant available water from the plots where crop rotation had been practiced, can be attributed to the accumulation of crop residues and subsequent organic matter build up. Additionally improved plant available water content can be related to reduced water evaporation due to increased soil organic matter and water infiltration. These results supports the findings of Huang *et al.* (2003) who reported that conservation of moisture through crop rotation was as a result of residue accumulation.

4.5.4 Effects of crop rotation on soil biological properties

4.5.5 Soil microbial counts & microbial biomass

Table 15 presents the results of the microbial counts and biomass as influenced by the cropping type. The microbial counts ranged from 5.33 to 165.67 cfu / g of soil. There was a strong and positive relationship between microbial counts and biomass. While microbial biomass was not statistically different among the cropping type, microbial counts differed statistically the highest being in the maize mono-cropping and the lowest in the maize-groundnut with fertilizer. The microbial biomass ranged from 0.23 to 0.49 mg/g of soil (Table 15).

Table 15: Effect of the maize-groundnut rotation on microbial counts and biomass

Cropping type	Microbial Counts (cfu / g of soil)	Microbial Biomass (mg/g of soil)
Maize-G/nut rotation + No fertilizer-MP	60.67^{ab}	0.32^{a}
Maize-G/nut rotation + Fertilizer-MP	5.33^{b}	0.23^{a}
Maize mono-cropping + NO Fertilizer-MP	137.67^{ab}	0.45^{a}
Maize mono-cropping + Fertilizer-MP	165.33^{a}	0.49^{a}
Maize-G/nut rotation + NO Fertilizer-GP	129.33^{ab}	0.43^{a}
Maize-G/nut rotation + Fertilizer-GP	33.67^{ab}	0.27^{a}
G/nut mono-cropping + NO fertilizer-GP	12.67^{b}	0.23^{a}
G/nut mono-cropping + Fertilizer-GP	71.33^{ab}	0.33^{a}
Least Significant Difference (LSD)	144.26	0.27
Coefficient of Variation (CV %)	108.24	45.1

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

Microbial biomass is a portion of soil organic matter and is therefore is strongly influenced by soil organic matter management. Soil organic carbon C strongly affects the amount and activity of soil microbial biomass (Jenkinson, 1988; Paul, 2007). However the results of this study did not show any relationship between soil microbial counts and biomass and soil organic matter. The variations in microbial counts and biomass can also be linked to the findings of Marshner *et al.* (2001) who reported that root exudates from different plants and even different cultivars of the same plants differed, and these may have a positive or negative influence the microbial biomass.

4.5.6 Groundnut nodulation

The number of nodules per plant ranged from 496 to 1129 nodules. The highest number of nodules was observed from groundnut mono-cropping treatments with fertilizer application (Table 16). The lowest was from the maize-mono-cropping without fertilizer. These results indicated that cropping patterns had significant effect ($P < 0.05$) on the number of nodules.

In general, the groundnut cropping had higher nodule counts as compared to maize cropping. This could be attributed to possibly higher populations of *Rhizobia* associated with groundnuts in these soils compared to where only maize has been repeatedly grown. The results also showed higher numbers of nodules in soils where fertilizer was applied. This could be attributed to the fact that while groundnut is a legume that is capable of fixing nitrogen, it requires starter nitrogen fertilizer for good establishment. In this case, higher number of nodules can be linked to the good root establishment which provided a larger root volume for *Rhizobia* infection and nodule initiation. These results are in agreement with the findings of Ritchie (1989) who reported that the addition of reduced quantity of inorganic N fertilizer to soils resulted in a relative increase in number of nodules.

Additionally Richie (1989) further observed that ammonification of organic matter such as legume residues does not directly lead to acidification which may affect microbial activity. However other authors have observed that groundnut is a good nitrogen fixer and usually does not respond to nitrogen fertilizers as long it is able to fix nitrogen (Kennedy, 1992). The application of fertilizer can be linked to the reduced number of nodules because legumes tend not to invest their energy resources in the process of nitrogen fixation and nodule formation when there are adequate supplies of nitrogen in the soil.

High initial soil nitrogen has also been linked with reduced nitrogenase enzyme production and activity in the nodules resulting in not only fewer nodules but also reduced nodule weight and effectiveness (Mweetwa *et al.,* 2016). The inhibitory effect of NO_3 on nodules has been recognized by Rhizobiologist and has been under investigation. People *et al.* (1989) in their separate findings attributed the effect of nitrogen on nodulation to the inhibition of rhizobium infection process via the impairment of the recognition mechanism by nitrates.

Table 16: Effects of the maize groundnut rotation on nodulation

Cropping type	No. of nodules per plant	Weight of nodules (g/plant)
Maize-G/nut rotation + No fertilizer-MP	496^{c}	1.92^{b}
Maize-G/nut rotation + Fertilizer-MP	584^{c}	2.05^{b}
Maize mono-cropping + NO Fertilizer-MP	508^{c}	1.92^{b}
Maize mono-cropping + Fertilizer-MP	633^{bc}	2.0^{b}
Maize-G/nut rotation + NO Fertilizer-GP	734^{bc}	1.76^{b}
Maize-G/nut rotation + Fertilizer-GP	911^{ab}	3.36^{ab}
G/nut mono-cropping + NO fertilizer-GP	765^{bc}	2.95^{ab}
G/nut mono-cropping + Fertilizer-GP	1129^{a}	4.27^{a}
Least Significant Difference (LSD)	325	2.0518
Coefficient of Variation (CV %)	26.1	46.9

X* means followed by the same letter within a column are not statistically different at 95% confidence level.

4.5.7 Biological Nitrogen Fixation

The results on biological nitrogen fixation are presented in figure 4. The amount of nitrogen fixed ranged from 0.17 to 1.88 N %. The highest amount of nitrogen fixed was recorded from the maize-groundnut rotation with no fertilizer cropping sequence (Table 14). The results indicated that there were significant differences among the cropping patterns.

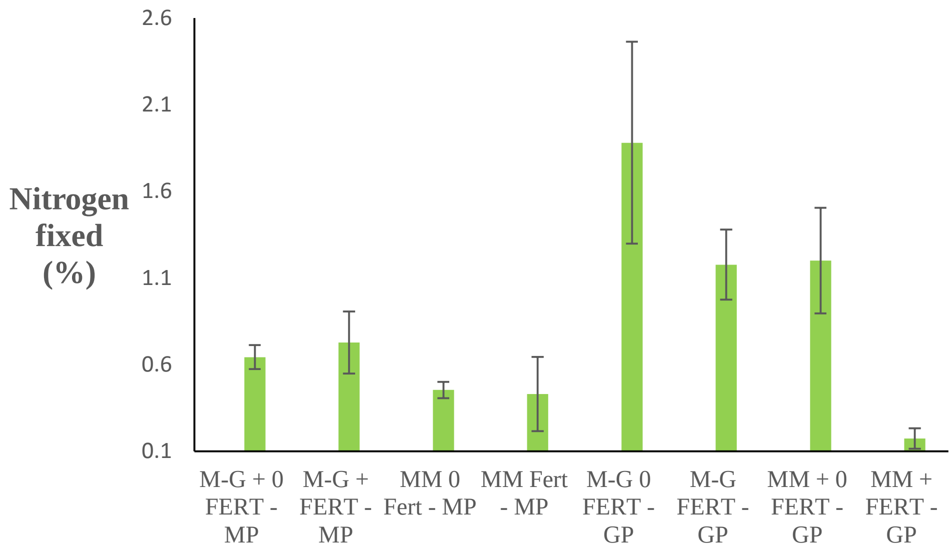

Figure 4: Biological fixation of groundnut in soils under maize-cowpea rotation and mono-cropping

The results also revealed that the level of nitrogen fixed was not dependant on the number of nodules present on the plants, this is because there was no relationship between nodulation and the amount of nitrogen fixed ($r^2 = 7 \times 10^{-8}$; data not shown). These findings are in agreement with the findings of Mweetwa *et al.* (2014) who reported that there was no positive correlation between nodulation and amount of nitrogen fixed. In addition they also concluded that not all nodules are capable of fixing nitrogen. When ineffective populations of rhizobia exits in the soil, high numbers of effective rhizobia should be provided (Dearker *et al.*, 2004).

4.5.8 Maize yield

Results on maize yield as influenced by the maize-groundnut rotation and mono-cropping are presented in figure 5. The maize yield values ranged from 0.57 to 1.64 tonnes per hectare. The highest yield was recorded from the maize-groundnut rotation with fertilizer. While the lowest maize yield was recorded from the maize mono-cropping without fertilizer application. The general trend was that maize yields were higher in the treatments where crop rotation was practiced than in mono-cropped treatments. The results showed that crop rotation had significant effect ($p < 0.05$) on the cropping sequences that were under investigation.

The current study results are in agreement with the findings of Zoltan *et al*. (2000) who reported higher maize yields in crop rotated treatments than in mono-cropped treatments in a long term rotational experiment which was done in South America. Similarly Peter (2007) reported that maize grain yields were increased up to 0.7 ton ha^{-1} following groundnut compared with continuous maize when no fertilizer was applied to both cropping systems. Maize yield responded well to N-fertilizer application after groundnut than continuous maize mono-cropping.

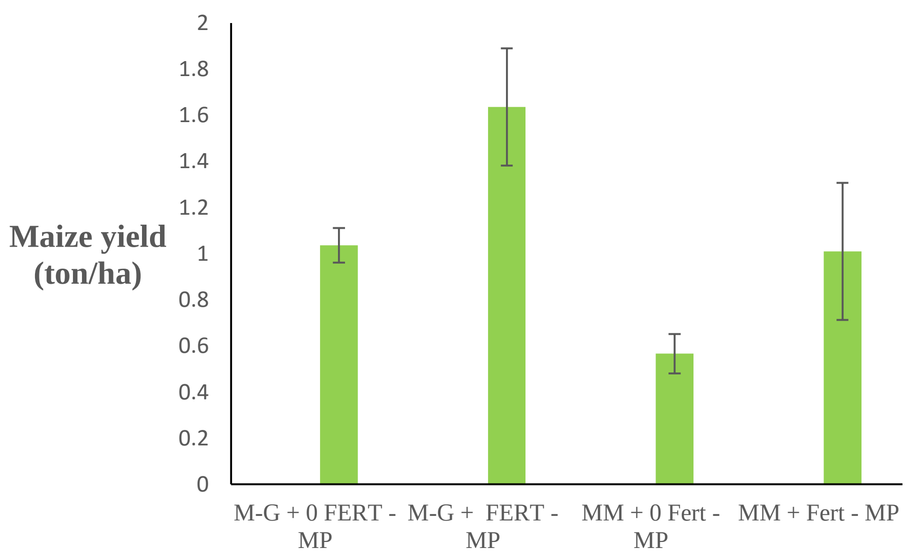

Figure 5: Maize yields from the maize-groundnut rotation and maize mono-cropping soils

Du Plessis (2003) also reported increased maize yields in conservation farming fields in Eastern. Free State in South Africa. Based on many long term field experiments Farooq *et al*. (2011) also showed that maize yields produced from conservation farming improved over time relative to conventional farming. These relative yield increases have been attributed to improved soil conditions under residue retention. Crop residues directly increases the input of organic matter and nutrients in the soil in turn improving soil nutrient availability for crop growth (Chengyan *et al.*, 2014).

However, Kirkgard (1995) reported non-significant yield differences between conservation and conventional farming and even a declining trend under CF over time, owing to the failure to control weeds and diseases. Even if CF practices may not have positive effects on crop yield, in some areas they are still meaningful. They have been recommended as an environmentally friendly technology that is very effective in reducing soil erosion and water loss.

CHAPTER FIVE: CONCLUSIONS

Conservation farming encompasses three basic principles; minimum soil disturbance, residue retention and crop rotation. In this study the focus was on crop rotation. The maize groundnut rotation (10 years of practice) had variable and reductive effects on zinc, sulphur, copper and iron while molybdenum was not significantly affected by the cropping types. Similarly in the maize-cowpea rotation (4 years of practice) soil nitrogen, zinc. Sulphur, copper and iron were affected by the cropping pattern, while molybdenum was not affected. The maize-groundnut and maize-cowpea rotation had no significant on soil reaction and exchangeable bases (calcium, magnesium and sodium). These principal findings which emerged from this study, imply that rotations involving only a cereal and a legume, both in the short and long term have reductive effects on micronutrients zinc, copper, sulphur and iron.

The physical parameters in the maize-groundnut rotation, were not significantly affected with an exception of plant available water which varied among the cropping patterns. Similarly maize-cowpea rotation had no significant ($p < 0.05$) effect on the physical variables except plant available which significantly varied among the cropping patterns.
The biological properties, in the maize-groundnut rotation, number of nodules, biological nitrogen fixation and maize yield were affected by the cropping pattern. However in the maize-cowpea rotation microbial biomass, number of nodules, weight of nodules, biological nitrogen fixation and maize yield were significantly reduced ($p < 0.05$) by the cropping pattern. Microbial counts in the maize-cowpea rotation was not significantly affected by the cropping pattern. The study showed that the maize-cowpea rotation had variable effects on the biological properties

As seen in the maize-groundnut rotation, most of the important soil properties were not significantly affected thus this cropping pattern should be encouraged in cropping systems. The maize-cowpea rotation had a higher yield than the maize-groundnut rotation. The combined use of crop rotation, crop residue retention and fertilizer application should be considered to be effective in improving soil nutrient status, particularly N and P in ensuring sustainable agriculture. Promoting the practice of residue retention and crop rotation practice even without addition of N fertilizer has a potential in increasing soil total N, soil organic carbon and enhancing availability of P. In this study it was deduced that crop residue retention under conservation farming has the potential in soil fertility restoration.

CHAPTER SIX: RECOMMENDATIONS

If the benefits of crop rotation involving only a cereal and a legume are to be fully realized, there is need to identify and use legume varieties that produce adequate biomass, have high biological nitrogen fixation capacities and have a low nitrogen harvest index ratio. The cereal crop to be used in the rotation must also be able to produce adequate biomass. It is also imperative to ensure sufficient available phosphorus in the soil if the legume rotations are to be optimized. Additionally farmers must be aware that the benefits of rotating only two crops a cereal and a legume may be more evident after a considerable long period preferably ten years and above. Integrated cropping systems and use of crop residues as sources of nutrients should be encouraged to improve soil productivity. Farmers should also recognize that organic and mineral fertilizers should be used together to complement each other and not replace each other. Despite the large body of information that clearly indicates that crop rotation improves soil quality and maize yield there is need to further investigate crop rotations involving more crops in a rotation. There is need to further evaluate the effects of the maize-cowpea rotation type which had minimal effects on the soil as compared to the maize-groundnut rotation.

The benefits of conservation farming are greatly influenced by the prevailing climatic conditions of a location. In the current situation where there are problems related to climate change such as constant droughts, socio-economic and farm management challenges, inclusion of legumes in maize based systems can help improve yields and reduce reliance on external inputs. It is therefore, recommended that similar studies be conducted over a wider range of soil properties in the various agro-ecological regions of Zambia in order to gain a better understanding of the effects of crop rotations on soil quality so as to make the results of the current study to be conclusive.

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APPENDICES

Appendix 1: Analysis of variance table for the maize-cowpea rotation

Parameter	df	MSE	F - Value	P-Value	Status
Soil reaction	12	0.03562500	1.47	0.2727	NS
Phosphorus	12	32.3541667	2.12	0.1505	NS
Nitrogen	12	0.00008750	4.76	0.0207	S
Organic carbon	12	0.03976875	1.69	0.2229	NS
Calcium	12	0.39901042	0.75	0.5441	NS
Magnesium	12	0.21210417	0.12	0.9449	NS
Sodium	12	0.00032292	0.12	0.9450	NS
Potassium	12	0.01072083	3.28	0.0584	NS
Zinc	12	0.22916667	3.91	0.0369	S
Copper	12	1.29166667	1.94	0.1777	NS
Manganese	12	2288.70833	0.56	0.6540	NS
Iron	12	98.621875	2.86	0.0813	NS
Sulphur	12	15.5429167	14.94	0.0002	S
Cation exchange capacity	12	0.91375000	0.58	0.6404	NS
Bulk density	12	0.00670208	0.43	0.7345	NS
Total porosity	12	9.5920021	0.41	0.7463	NS
Infiltration rate	12	0.01033750	0.20	0.8911	NS
Plant available water	12	0.00161042	2.21	0.1399	NS
Microbial counts	12	8390.0625	2.25	0.1351	NS
Microbial biomass	12	0.01911875	3.65	0.0444	S
Number of nodules	12	28.395833	110.94	0.0001	S
Weight of nodules	12	0.06221458	11.05	0.0009	S
Biological nitrogen fixation	12	0.23539792	5.03	0.0175	S
Yield	12	252328.23	9.38	0.0018	S

Note: NS stands for Non-significant & S stands for significant.

Appendix 2: Analysis of variance table for the maize-groundnut rotation.

Parameter	df	MSE	F - Value	P-Value	Status
Soil reaction	16	0.12375000	0.75	0.6320	NS
Phosphorus	16	92.958333	2.22	0.0879	NS
Nitrogen	16	0.00014583	1.03	0.4492	NS
Organic carbon	16	0.04379169	1.65	0.1916	NS
Calcium	16	5.0148958	0.69	0.6830	NS
Magnesium	16	1.479001250	0.52	0.8038	NS
Sodium	16	0.00775000	0.75	0.6327	NS
Potassium	16	0.00930417	0.94	0.5041	NS
Zinc	16	0.26833333	6.33	0.0011	S
Copper	16	2.20833333	1.63	0.1981	NS
Manganese	16	5266.2917	0.44	0.8608	NS
Iron	16	479.65125	1.33	0.3005	NS
Sulphur	16	124.275000	2.68	0.0484	S
Cation exchange capacity	16	10.0062500	0.60	0.7458	NS
Bulk density	16	0.01156667	0.65	0.7064	NS
Total porosity	16	16.2236458	0.67	0.6941	NS
Infiltration rate	16	0.02006250	0.95	0.4983	NS
Plant available water	16	0.00094583	13.83	0.0001	S
Microbial counts	16	6946.5833	1.58	0.2106	NS
Microbial biomass	16	0.02382083	1.3	0.3125	NS
Number of nodules	16	35325.000	3.97	0.0106	S
Weight of nodules	16	1.405515833	1.75	0.1667	NS
Biological nitrogen fixation	16	0.21038333	4.36	0.0071	S
Yield	16	61878.193	19.68	0.0001	S

Note: NS stands for Non-Significant & S stands for significant.