EFFECTS OF CONSERVATION AGRICULTURE ON ECOSYSTEM SERVICES AND ITS ADOPTION BY VULNERABLE RURAL COMMUNITIES OF KENYA AND TANZANIA

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A thesis submitted in fulfilment for the award of Doctor of Philosophy Degree in Environmental Science of Masinde Muliro University of Science and Technology

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DECLARATION

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

Sign: ……………………………… Date: ……………………………….

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a thesis entitled ‘Effects of Conservation Agriculture on Ecosystem Services and its Adoption by Vulnerable Rural Communities of Kenya and Tanzania’.

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DEDICATION

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ABSTRACT

Agriculture has fundamentally changed human society and demand for its products is ever increasing. Meanwhile, a quarter of Earth's ice-free land area is subject to human-induced degradation, with agriculture driving about 70% of terrestrial biodiversity loss. Land degradation is enhanced by plough- and hoe-based agricultural practices. Climate change exacerbates it, crop yields for rainfed agriculture by vulnerable small-scale farmers have decreased. To control these environmental impacts caused by conventional intensification of agriculture and climate change impacts, there is urgent need for transition to farming systems that ensure food security and protect ecosystem services on which agriculture depends. Conservation Agriculture (CA) has been identified as environmentally and socially sustainable solution to match the growing food demand to its supply. It harnesses biodiversity and optimizes ecosystem services by applying three principles; minimum mechanical soil disturbance, permanent soil cover, and crop rotation. A field experiment was conducted to evaluate how CA enhances ecosystem services of maize production, biodiversity conservation, and soil health improvement, a social survey was also conducted to understand adoption of CA by small scale farmers. Six tillage systems; three of which are conservation (animal ripping, tractor ripping, and hand basins), and the other three (animal plough, tractor plough and hand ridges) conventional; were established in a main plot of 30 m by 10 m and subdivided into three subplots of 10 m by 9 m which were covered with either 5 cm thick grass mulch, 5 cm thick rice husks, and control with no mulch. A Randomized Complete Block Design was used with three replicates. Fertilizer treatments were uniform and C.P.201 hybrid maize seeds were planted at a population of 44000 ha^{-1} in all plots. Glyphosate was applied in conservational tillage plots to remove weeds while manual weeds removal was used in conventional tillage plots. The effects of conservation and conventional tillage and soil cover on maize yield, soil macro and microorganisms, and soil chemical properties were assessed. Soil cover significantly increased maize grain weight ($p = 0.001$, 0.04 and 0.03) and biomass ($p = 0.006$, 0.002 and 0.094) in the three cropping seasons. Conservation tillage with grass mulch had higher macro-organisms' diversity with Diversity Index (D) = 0.476, 0.233 and 0.282 for season one, two and three respectively. There was no significant difference in abundance of microorganisms between conservation and convention tillage as well as soil cover treatments. Tillage treatments increased soil organic carbon but there was a general decline in the other mineral elements with season. However, all the mineral elements measured were below the critical levels for maize except potassium. Adoption of CA was affected by land size, yield levels, and social-economic factors. Level of education and conservativeness of farmers are the common to ranking factors affecting adoption on CA in Kenya and Tanzania. Lack of awareness and negative attitude are important factors specific to Tanzania while for Kenya is low-income levels and little or no involvement of women in decision making.

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ACRONYMS AND ABBREVIATIONS

CA	Conservation Agriculture
AGRA	Alliance for Green Revolution in Africa
CC	Climate Change
CFU	Colony-forming Unit
CIMMYT	International Maize and Wheat Improvement Centre
CO_2	Carbon Dioxide
CSA	Climate-Smart Agriculture
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	Conventional Tillage
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Production
GHG	Green House Gases
KALRO	Kenya Agricultural and Livestock Research Organisation
LAMP	Land Management Programme
MVIWATA	Muungano wa Vikundi vya Wakulima Tanzania
NEPAD	New Partnership for Africa's Development
OECD	Organisation for Economic Co-operation and Development
ROK	Republic of Kenya
SARI	Selian Agricultural Research Institute
SCAPA	Soil Conservation and Agroforestry Programme in Arusha
SIMLESA	Sustainable Intensification of Maize-Legume Systems for Food Security in Eastern and Southern Africa
SMB	Soil microbial biomass
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub Saharan Africa

TFSC	Tanzania Farmers Service Centre
TMA	Tanzania Meteorological Agency
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
WCCA	World Congress on Conservation Agriculture

OPERATIONAL DEFINITION OF TERMS

Climate change adaptation	This is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In this study, climate change adaptation means the planned adaptation which is, as a result of deliberate policy decisions, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve the desired state.
Climate change mitigation	This consists of actions to limit the magnitude or rate of long-term global warming and its related effects. It generally involves reductions in human emissions of greenhouse gases. Conservation agriculture is promoted among large scale farmers as mitigation towards climate change when they reduce the use of motorized machines for tillage.
Conservation tillage	Conservation tillage is any method of soil cultivation that leaves the previous year's crop residue (such as corn stalks or wheat stubble) on fields before and after planting the next crop to reduce soil erosion and runoff, as well as other benefits such as carbon sequestration.

Conventional tillage	Conventional tillage is the soil cultivation using plough or hoe as the major means of seedbed preparation and weed control. It includes a sequence of soil tillage, such as ploughing and harrowing, to produce a fine seedbed, and also the removal of most of the plant residue from the previous crop.
Ecosystem Services	Ecosystem services are the many and varied benefits to humans provided by the natural environment and from healthy ecosystems. Such ecosystems include, for example, agroecosystems, forest ecosystems, grassland ecosystems and aquatic ecosystems. The services are divided into four categories: provisioning, regulating, cultural and supporting.
Mulch	The organic crop residues that are kept on the soil surface, not only to protect the soil from raindrops but also to enhance infiltration, avoid weed development and provide nutrients to the soil. In this study grass and rice husks mulches were used as a demonstration of retention of crops residue advocated for in conservation agriculture.
Reduced tillage	Reduced tillage covers a range of tillage practices that do not involve inverting the soil, they minimize soil disturbance and crop residues are left on the soil. For

	example, in this study hand basins and ripping both tractor and animal were applied.
Soil Health	Soil health is a state of a soil meeting its range of ecosystem functions as appropriate to its environment, caused by favourable interactions of all soil components (living and non-living) that belong together, as in microbiota, plants and animals.
Tillage	Tillage is the physical, chemical or biological manipulation of soil to optimize conditions for germination, seedling establishment, and crop growth. This study had varied conservation or reduce tillage and conventional tillage as the main treatments in the experiment.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The Intergovernmental Panel on Climate Change (IPCC) special report on *Climate Change and Land* outlines the fact that land provides the principal basis for human livelihoods and well-being including the supply of food, fresh water, and multiple other ecosystem services, as well as biodiversity (IPCC, 2019). People currently use one quarter to one-third of land's potential net primary production for food, feed, fibre, timber, and energy. Land provides the basis for many other ecosystem functions and services, including cultural and regulating services, that are essential for humanity. In one economic approach, the world's terrestrial ecosystem services have been valued on an annual basis to be approximately equivalent to the annual global Gross Domestic Product (IPCC, 2019). However, agriculture has fundamentally changed human society since the first people started domesticating plants and animals for food more than 10 000 years ago. Global demand for agricultural products is expected to double in the coming decades (Godfray et al., 2010), as the human population grows in both size and affluence (FAO, 2014; Foley et al., 2011; Godfray et al., 2010; Herrero et al., 2010; Pretty, 2007). The growth of the global population has been supported by advances in agricultural production, but at the same time, this increased population is having a major impact on the climate which in turn impacts our ability to produce crops.

Over the past half-century, due to the grown demand, there has been both an expansion of agriculture around the world (Foley et al., 2011) and an increased adoption of conventional intensification through larger fields of monoculture crops and greater external inputs, pioneered during the Green revolution (Garibaldi et al., 2017; Pretty, 2007). Agricultural intensification based on tillage-based agriculture, has, at all levels of economic development, had a negative effect on the quality of the essential natural resources such as soil, water, terrain, biodiversity and the associated ecosystem services provided by nature (Kassam et al., 2019).. Conventional intensification has been the mainstream strategy for agricultural development for decades (Connor, 2008), but has become a major environmental pressure (Reganold & Wachter, 2016). The conventional paradigm has been to maximize crop yield, which, some argue, has decreased the rate of agricultural expansion, saving land for natural habitats and other uses (Stevenson et al., 2014). Another possibility is that an increase in crop yield augments the profitability of land conversion and leads to further agricultural expansion (Ceddia et al., 2014; Lambin & Meyfroidt, 2011; Laurance et al., 2014; Tscharntke et al., 2012). Agriculture is considered the driver for around 70% of the projected loss of terrestrial biodiversity globally (Convention on Biological Diversity, 2014). Equally, agriculture is a major contributor to greenhouse gas emissions, although there is disagreement to the extent of this contribution, with estimates ranging from 10% to 45% of global anthropogenic emissions (Ethiopian Panel on Climate Change, 2015; IPCC, 2007; UNCTAD, 2013). About a quarter of the Earth's ice-free land area is subject to human-induced degradation. Soil erosion from agricultural fields under conventional tillage is estimated to be currently more than 100 times higher than the soil formation rate (Barton et al., 2004). Land degradation is enhanced by the use of plough-based and hoe-based agricultural practices. These practices make soil denser and more compact, leading to decreases in organic matter content, while water runoff and soil erosion increase (Mtakwa et al., 2019). Moreover, the current demands from agriculture on the fresh water resources of the world, in addition to desertification, salinization, soil erosion, and other consequences of unsustainable management, are of major concern (FAO, 2014; Godfray et al., 2010; Reganold & Wachter, 2016).

Overarching all of these issues is the threat of the effects of substantial climate change and concerns about how mitigation and adaptation measures may affect the food system (Parry et al., 2007). The challenge now is to match the rapidly changing demand for food from a larger and more affluent population to its supply in ways that are environmentally and socially sustainable. This challenge requires changes in the way food is produced, stored, processed, distributed, and accessed that are as radical as those that occurred during the 18th- and 19th-century Industrial and Agricultural Revolutions and the 20th-century Green Revolution. Increases in production will have an important part to play, but they will be constrained as never before by the finite resources provided by Earth's lands, oceans, and atmosphere (Godfray et al., 2010). Climate change exacerbates land degradation, particularly in drylands. Over the period 1961-2013, the annual area of drylands in drought has increased, on average by slightly more than 1% per year, with large interannual variability, affecting Sahara region the most (IPCC, 2019). These changes in climate cause negative impacts on average crop yields and increases in yield variability. Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the period 2030–2049 showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century. After 2050 the risk of more severe yield impacts increases and depends on the level of warming (Burke et al., 2009).

In view of these widespread environmental impacts from the conventional intensification of agriculture and the impacts of climate change, there is considerable agreement on the urgent need for a global transition to farming systems that ensure food security and nutrition, provide social and economic equity, and build and protect the ecosystem services on which agriculture depends (Barrett, 2010; DeFries et al., 2015; FAO, 2014; Garnett et al., 2013; Godfray et al., 2010; United Nations, 2015). This has led to the promotion of several alternative approaches that harness, rather than supplement, ecosystem services provided by biodiversity (such as nutrient cycling, pest control, or pollination) to achieve resilient and productive farms (Bommarco et al., 2013; Reganold & Wachter, 2016; Tittonell & Giller, 2013; Wezel et al., 2015). Numerous global initiatives support these alternatives as foundations for global shifts in agricultural practices, such as the UN2030 Agenda for Sustainable Development (United Nations, 2015) and the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES).

Land degradation in agriculture systems can be addressed through sustainable land management, with an ecological and socioeconomic focus, with co-benefits for climate change adaptation. Management options that reduce vulnerability to soil erosion and nutrient loss include growing green manure crops and cover crops, crop residue retention, reduced/zero tillage, and maintenance of ground cover through improved grazing management (IPCC, 2019). In this dispensation of climate change and its potentially negative impacts on smallholder farming systems, there is a need to adopt Climate Smart Agriculture (CSA). The long term climate forecasts for the sub-Saharan region indicate that increased heat stress and erratic rainfall will occur due to an increase in average temperature (Burke et al., 2009; Cairns et al., 2012, 2013); factors that will potentially affect crop production (Lobell et al., 2008). Crop productivity on many smallholder farms in sub Saharan Africa is invariably low due to soil fertility decline, insufficient and inappropriate fertilizer application, unreliable rainfall and a variable climate, lack of improved cultivars, labour constraints, and in some situations inappropriate tillage practices (Morris et al., 2007; Sanginga & Woomer, 2009; Wall et al., 2013; Winterbottom et al., 2013). As a result, a greater proportion of farmers remains trapped in abject poverty, are food insecure and malnourished (Sachs et al., 2004; Tittonell & Giller, 2013).

Smallholder farming dominates agriculture in Sub-Saharan African (SSA) operating on less than 2 hectares in total landholding (Cairns et al., 2013). These are the farmers that supply the urban population with food as well as contribute to the national economies of their individual countries. Yet, smallholder agriculture is constrained by many inter-related factors including low soil fertility, frequent dry spells, drought, and unsustainable management practices. Traditional agricultural practices have diminished soil productivity to the extent that many agricultural soils are depleted of nutrients and unable to naturally sustain crop productivity. In the coming decades, a crucial challenge for agriculture in SSA will be meeting food demands without undermining further the environment (Naab et al., 2017a). Increasing productivity and economic returns to smallholder farming in a sustainable manner is a central challenge to achieving global poverty reduction and environmental management objectives (FAO, 2012a).

Advances in agricultural productivity have supported the growth of nations, while the failure of agricultural systems has led to famine and societal unrest. Climate change already impacts agricultural production and action is needed if we are to continue to feed the growing human population (Edwards, 2018). Agriculture is normally characterized by high variability of production outcomes, also known as production risk. Production risk is associated with negative outcomes caused by unpredictable events that affect crop production, such as disease, pests, and extreme weather events (Kidane et al., 2019). Farming systems in sub-Saharan Africa are characterized by substantial exposure to external risks to crop production. Compounding these external risks are the effects of climate change, soil degradation, and soil fertility decline that mandates developing sustainable intensification practices to address these issues. Similarly, maize production in Kenya and Tanzania is highly dependent on rainfall. Consequently, 73% of the risk associated with maize crop failure has been attributed to drought (Kidane et al., 2019).

Continuous cropping and inadequate replacement of nutrients removed in harvested materials, or on-site burning of crop residues, and through erosion have hastened soil degradation in Kenya and Tanzania. Besides low soil fertility, drought, erratic rainfall, and climate change are frequently mentioned by farmers as constraints to crop production. The risk of moisture stress, affects crop production across the semi-arid tropics of sub-Saharan Africa, between 70% and 85% of rainfall is lost to surface runoff, deep drainage and evaporation rather than being used by crops for productive transpiration (Rockström et al., 2002). As a result of global warming and climate change, increased variability of seasonal distribution of rainfall is expected throughout the region coupled with a reduction in rainfall in much of the region (Lobell et al., 2008), factors that will aggravate the inefficiencies in rainfall use noted above. Declining yields and environmental problems are associated with many agricultural systems. According to (FAO, 2014), crop production levels in Tanzania are generally below potential. Many farmers associate these low yield levels with poor inherent soil fertility and continuous cultivation with few, if any, inputs. However, it is generally understood and well documented that conventional farming practices with frequent ploughing gradually degrade the physical structure of tropical soils (Brady & Weil, 2007), leading to increased soil erosion and decreased chemical quality of tropical soils (Wall et al., 2013).

East Africa tops the list of Sub Saharan Africa regions affected by land degradation, a long-term decline in ecosystem function measured in terms of net primary productivity (Bai et al., 2008) closely linked to rural household food insecurity and poverty (Malley et al., 2006). The causes of land degradation are inappropriate tillage and cropping systems which have resulted in soil organic carbon (SOC) and soil structural reduction (Wall et al., 2013). Although tillage with a hand hoe accounts for 80% of the cultivated area in East Africa (Sims et al., 2012), this still results in soil structural breakdown and the formation of hardpans and severe hardpans are common in manually cultivated farms (Wall et al., 2013). Soils are natural resources of utmost importance for a number of ecosystem and biosphere processes such as plant production, cycling of organic matter and nutrients, storage of carbon and water, and release of nitrous oxides, CO_2 and methane. Soil degradation, through various processes, is a matter of great concern, since their integrity is absolutely critical to increasing food production. Concern for the loss of biodiversity in soils is closely linked to the possible role of species in the protection of the productive potential.

These challenges can be addressed by identifying, promoting, and realizing widespread and durable adoption of technologies for sustainable agricultural intensification. Conservation agriculture is one such approach that aims to sustainably improve farm productivity, profits, and food security (FAO, 2012). Since the 1990s, cropping systems based on a combination of no-tillage, mulch cover from living or dead plants, and diversified crop rotations and associations have been promoted as a possible solution to these constraints in Africa (FAO, 2002; Haggblade & Tembo, 2003; Kassam et al., 2009). This system was later defined as conservation agriculture (FAO, 2002; Haggblade & Tembo, 2003; Kassam et al., 2009) .

The term “Conservation Agriculture” was coined in the late 1990s, just before the 1st World Congress on Conservation Agriculture (WCCA) in Madrid in 2001. There is considerable diversity in approaches and understandings of conservation agriculture to-date, but in general, it revolves around three principles: no-till (or minimal mechanical soil disturbance), soil cover and crop rotation (FAO, 2001; Kassam et al., 2014; Thierfelder & Wall, 2009). In sub-Saharan Africa, Conservation Agriculture is considered an approach to increase food security, alleviate poverty, conserve biodiversity, safeguard ecosystem services and support climate change adaptation and mitigation (Pomeroy & Aljofre, 2012). It is a powerful mechanism to adapt to climate change by increasing resilience to drought since it enhances moisture retention hence helps to alleviate dry spells (Rosenstock et al., 2018). Conservation agriculture is considered climate-smart agriculture and was listed by IPCC as one of the actions with co-benefits towards adaptation to climate change (IPCC, 2014). It improves ecosystem services, with focus on soil health, on-farm biodiversity conservation and food production. At the same time, it increases productivity and efficiency use for land, water, and energy, and curbs the many negative effects of food production on the environment (Godfray et al., 2010; Kassam, Derpsch, et al., 2014; Kassam, Friedrich, et al., 2014).

Conservation agriculture, which may be defined as resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (Van den Putte et al., 2010), has become more and more important globally. Conservation agriculture practices are being widely promoted in many areas in sub-Saharan Africa mainly for maize-based farming systems to recuperate degraded soils and improve ecosystem services (Thierfelder & Wall, 2009). Since smallholder agriculture in sub-Saharan

Africa is characterized by mouldboard ploughing and hand-hoeing that is often thought to lead to land degradation and excessive nutrient loss, conservation agriculture is now considered as potential to combat this scourge (Fowler & Rockstrom, 2001; Knowler & Bradshaw, 2007). It aims to make better use of agricultural resources through the integrated management of available soil, water, and biological resources, combined with limited external inputs.

The benefits of conservation agriculture have been well document, particularly in southern Africa. However, little is known about its perceived benefits in Kenya and Tanzania, particularly on the ecosystem services it enhances, including soil health improvement, on-farm biodiversity conservation, and maize production levels. The objective of this study was to evaluate the various ecosystem services that are harnessed by Conservation Agriculture Systems including food production, soil health improvement, and biodiversity conservation. This study was motivated by the hypothesis that rural vulnerable communities would benefit more by adopting conservation agriculture approaches as opposed to the conventional tillage approaches that small-scale farmers use. There has been active promotion and awareness creation of conservation agriculture to farmers in Kenya and Tanzania. However, adoption rate is still very low. This study also carried out a social survey to establish the factors that affect its adoption. The study ran for 24 months and the results are presented herewith.

1.2 Statement of the problem

Small scale farmers are the main food producers in sub-Saharan Africa. In Kenya, this makes about 80% of the farmers. They hold small pieces of land 5 acres and below, and they mostly depend on rain-fed crop production which is increasingly becoming unreliable due to changing rain patterns. In Tanzania, small scale farmers access much bigger pieces of land, but the production level is very low. Environmental degradation due to poor agricultural practices like conventional tillage and uncovered soil surface has compounded the problem and reduced land potential in food production. This results in a high cost of production, low production rate per hectare and increased vulnerability to climate change impacts.

Given the small land size factor, growing need for food to feed the increasing human population, and climate instability, smallholder farmers are at a fix to find approaches that will reduce food production cost at the same time increasing food production. The priority of small-scale farmers is food production for family subsistence, returns on inputs especially of seed and fertilizer, and reduction of drudgery, especially on women. The three priorities of small-scale farmers mentioned above are enhanced through conservation agriculture which has been proven to reduce production costs, maintain soil fertility and conserve soil moisture. Crop residues left on the field, mulch and special cover crops protect the soil from erosion and limit weed growth throughout the year.

Ecosystem services that accrue from conservation agriculture such as increased food production, enhanced biodiversity, soil fertility and moisture conservation, have the potential to improve our environment if farmers get to know and adopt the practice. The services have however not been quantified in Morogoro, Tanzania and in Bungoma, Kenya to a level where the information can be used to inform policy processes that would, therefore, promote conservation agriculture across the region. This study seeks to fill the gap in the quantification of the ecosystem services accrued from conservation agriculture and at the same time explore the challenges that face its adoption in the region.

1.3 Justification

Food production must increase to meet the needs of a growing population whilst minimizing impacts on the environment. This requires sustainable intensification of agriculture, and Conservation Agriculture has been highlighted as a key route to sustainable intensification. Conservation Agriculture practices are also considered potential in making agricultural systems more resilient to climate change, reduce the farming systems' greenhouse gas emissions and enhance their role as carbon sinks. It is, therefore, significant to scientifically evaluate whether this is true for rural Kenya and Tanzania where the population is in dire need of solutions and direction to climate risk and food insecurity.

There is good knowledge about Conservation Agriculture in terms of adopting it as an agricultural approach. However, Conservation Agriculture represents a fundamental change to agricultural production systems. It potentially has many benefits that provide an indication of why farmers over the world are increasingly adopting conservation agriculture and why it deserves greater attention from the research and development community. Nevertheless, the many synergistic interactions between components of conservation agriculture practices are not yet fully understood. In general, scientific research on conservation agriculture systems lags behind what farmers are discovering and adapting on their own initiative. This is partly because conservation agriculture is a complex, knowledge-intensive set of systems which does not lend itself to easy scrutiny by a research community often driven by short-term reductionist thinking and approaches (Uphoff et al., 2006)

There is a gap in knowledge of how significant Conservation Agriculture is, in enhancing ecosystem services of landscapes in rural Kenya and Tanzania. This knowledge is needed to inform policy development particularly for vulnerable rural communities of small-scale farmers as they endeavour to adapt to challenges of climate change.

1.4 Objectives

The general objective of the study is to establish whether conservation agriculture improves ecosystem services (food production, biodiversity conservation, and soil health) to help vulnerable rural communities adapt to climate change

Specific objectives

The specific objectives of the study are: -

1. To determine to effects of conservation agriculture on maize yield
2. To assess effects of conservation agriculture on diversity and abundance of soil macro and microorganisms
3. To evaluate effects of conservation agriculture on soil health
4. To identify factors affecting the adoption of Conservation Agriculture among smallholder farmers in Kenya and Tanzania

1.5 Research questions

The research questions that the study seeks to address are;

1. Does conservation agriculture increase maize production levels?
2. Does conservation agriculture harness biodiversity conservation?
3. Does conservation agriculture improve soil health?
4. What influences the adoption of Conservation Agriculture by smallholder farmers in Kenya and Tanzania?

CHAPTER TWO: LITERATURE REVIEW

2.1 Background information

Agriculture is the backbone of the economy of many developing countries. Typically, it is the largest source of employment; often two-thirds or more of the population of developing countries are dependent on farming for their livelihood (FAO, 2016). In Sub-Saharan Africa, the agricultural sector has a pivotal role in employment, employing 65 percent of the total workforce (Organisation for Economic Co-operation and Developemnt, 2016). More than half of rural employment in Sub-Saharan Africa consists of self-employed farmers, many of whom are women. While its importance to the rural population is well documented, recent surveys suggest that agriculture is also the primary source of livelihood for 10% to 25% of urban households. National census data indicates that the number of people employed primarily in agriculture has increased over time (Yeboah & Jayne, 2015).

Agricultural growth in Sub-Saharan Africa has accelerated from 2.3 percent per year in the 1980s to 3.8 percent per year between 2000 and 2005 (World Bank, 2008). On average, agriculture in sub-Saharan Africa contributes 15% of total GDP, however, it ranges from below 3% in Botswana and South Africa to more than 50% in Chad (Organisation for Economic Co-operation and Developemnt, 2016), this implies a diverse range of economic structures. Agriculture, in this region, employs more than half of the total labour force (IMF, 2012, 2015) and within the rural population, provides a livelihood for multitudes of small-scale producers. Smallholder farms constitute approximately 80% of all farms in SSA and employ about 175 million people directly (AGRA, 2014). In many of the countries, women comprise at least half of the labour force (FAO, 2016).

In both Kenya and Tanzania, agriculture is the leading sector of the economy, it contributes significantly to the gross domestic product (GDP). In Tanzania, it accounts for about half of the national income, three-quarters of merchandise exports and employs 80 percent of the country population especially those in rural and peri-urban areas (United Republic of Tanzania, 2014). The report further states that it contributes 24.7% of Gross Domestic Production (GDP) and provides 95% of food requirements in the country. Recent data shows that in the year 2014, agriculture contributed 31.5% of GDP in Tanzania and 30.3% in Kenya (Organisation for Economic Co-operation and Development, 2016). Only 11% of land in Kenya has high potential agricultural production, although it is now degraded due to overutilization and other anthropogenic factors by the 62% of Kenyans population that live there (Alila & Atieno, 2006; Kanyinga, 2009; ROK, 2006). The other land which is 70% arid and 19% semi-arid, needs enhancement by appropriate farming approaches that are climate-smart and reduce prohibitive costs. Like Tanzania, in Kenya agriculture is driven by rural small-scale farmers, constituting 75% of total population, a majority of which are poor and vulnerable to climate change impacts (ROK, 2004). The sector provides livelihoods (employment, income, and food security needs) for more than 80% of the Kenyan population (ROK, 2006). These farmers need highly reliable approaches that promote environmental and livelihoods sustainability.

The important role of the agricultural sector in contributing to food security and livelihoods is evident from its high share in GDP the sector contributes in most countries in sub-Saharan Africa. Agricultural output growth in the region has accrued predominantly from area expansion and intensification of cropping systems, as opposed to large-scale improvement in productivity (Blein, 2013; Brink & Eva, 2009). Given that Sub-Saharan Africa is generally regarded as land abundant, continued area expansion in the coming decade may not seem problematic. However rural Sub-Saharan Africa is highly heterogeneous and while much of its land is unutilized or underutilized, a considerable share of its rural population resides in smallholder farming areas that are densely populated and face land shortages (Jayne et al., 2014). In a wider assessment that considers a combination of biophysical and economic factors as criteria for viability, (Chamberlin et al., 2014) indicate that potentially arable cropland is highly sensitive to assumptions related to land productivity and market access. Much of the underutilized land is concentrated in relatively few countries and between one half and two-thirds of surplus land is currently under forest cover. Conversion of such forest land to agriculture would come as considerable environmental cost.

Rising rural populations and associated land pressures have resulted in continuous cropping in many African countries, with fallows largely disappearing in densely populated areas. Continuous cultivation of existing plots would not necessarily pose problems for sustainable intensification if sufficient use of fertilizers, soil amendment practices, and other land-augmenting investments are employed and coupled with continued education to maintain and improve soil quality. However, a large body of literature in SSA points to soil degradation arising from unsustainable cultivation practices in regions with a high population density, for example parts of Kenya and Malawi (Drechsel et al., 2001; Lesschen et al., 2007; Tittonell & Giller, 2013). Continuous cultivation and lack of crop rotation deplete organic carbon levels, making soil less responsive to fertilizer application. This also makes it more difficult for smallholder farmers to benefit from yield gains offered by plant genetic improvement.

Considering the severity of the impact of the 2015 - 2016 drought on food security in the region, the potential impact of climate change cannot be ignored. The frequency of drought occurrence is already higher in Sub-Saharan Africa relative to most other regions in the world and agricultural production remains largely rain-fed (Organisation for Economic Co-operation and Development, 2016). While the precise impacts of climate change on African farming systems are likely to vary spatially in ways that are difficult to predict, two general predictions for which there is now some consensus are greater variability in agricultural production and a possible decline in crop productivity (Schlenker & Lobell, 2010). The evolution of both farm structures and farming practices in the region will impact on the resilience of increasing climatic variability in the future. Increasing the rate of technological adoption, facilitating access to irrigation systems and improved farming practices that support such resilience remains one of the greatest challenges facing the region. The Malabo Declaration of Africa Union, (Africa Union, 2014), on accelerated agricultural growth, strives to eradicate hunger in Africa by 2025. Among other objectives, it targets a doubling of agricultural productivity within the context of resilient agricultural systems. Conventional agricultural tillage systems will need to be rechecked.

Tillage, particularly in fragile ecosystems, was questioned for the first time in the 1930s. Soil tillage is the physical, chemical or biological manipulation of soil to optimize conditions for germination, seedling establishment, and crop growth. Concepts for reducing tillage and keeping soil covered came up as described in the historical review of no-tillage cultivation of crops (Friedrich et al., 2012). The term conservation tillage was introduced to reflect such practices aimed at soil protection. Seeding machinery developments allowed then, in the 1940s, to seed directly without any soil tillage. At the same time theoretical concepts resembling today's Conservation Agriculture principles were elaborated by Edward Faulkner in his book "Plowman's Folly", and Masanobu Fukuoka with the "One Straw Revolution" as described by modern researchers (Farooq & Siddique, 2015; Friedrich et al., 2012, 2017). But it was not until the 1960s that no-tillage entered farming practice in the USA. In the early 1970s no-tillage farming reached Brazil, where farmers together with scientists transformed the technology into the system which today is called Conservation Agriculture.

The degradation of agricultural soils in the world, and the consequent loss in soil health and their productive capacity, are the result of intensive tillage-based farming practices that pay inadequate or no attention to managing the soils and the landscapes as part of living biological and ecosystem resource base (Huggins & Reganold, 2008; Montgomery, 2012). Thus, most agricultural soils have low organic matter with poor soil aggregate structure, and there is little effort made by farmers to develop organic soil cover or mulch from crop residues, stubbles and green cover crops to feed the soil microorganisms, maximize rainfall infiltration, protect the soil from water and wind erosion. Soil degradation has caused agricultural yields in many parts of Africa to fall by up to 50% (E. L. D. Initiative & UNEP, 2015). One of the main causes of soil degradation identified in Africa by the ELD Initiative and UNEP, is inappropriate methods of soil preparation and tillage. This is characterized by intensive soil preparation using hand hoe or plough combined with removal or burning of crop residues (Rockström et al., 2009).

Tillage-induced soil erosion is responsible for 40 % of soil losses which amount to 150 tonnes ha^{-1} annually in Africa (FAO, 2001). It also results in mining soils of plant nutrients by removing crop residues and leaching. Thus, the intensive and continued use of the plough has proven to be unsustainable in several climatic zones (FAO, 2001). In many smallholder farming systems in Sub-Saharan Africa, there are competing demands on available crop residues, especially for livestock feed (Giller et al., 2009; Valbuena et al., 2012).

2.2 The Concept of conservation agriculture

The term Conservation Agriculture was adopted during the First World Congress on Conservation Agriculture, in Madrid the year 2001 (organized by FAO and the European Conservation Agriculture Federation (http://www.fao.org/ag/ca). In an account on overview of conservation agriculture, (Kassam et al., 2009), the three components of optimum Conservation Agriculture are: maintaining year-round organic matter cover over the soil, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop; secondly, minimizing soil disturbance by tillage and thus seeding directly into untilled soil, eliminating tillage altogether once the soil has been brought to good condition, and keeping soil disturbance from cultural operations to the minimum possible; thirdly, diversifying crop rotations, sequences and associations, adapted to local environmental conditions, and including appropriate nitrogen-fixing legumes; such rotations contribute to maintaining biodiversity above and, in the soil, contribute nitrogen to the soil/plant system, and help avoid build-up of pest populations.

The practice of Conservation Agriculture was developed in response to continuously declining land productivity under "conventional" soil tillage systems (FAO, 2001) and revolve around three principles of minimizing soil disturbance, maintaining a permanent organic soil cover and a system of crop rotations. Simultaneous application of these principles allows farmers to better manage available soil, water, and biological resources as well as farm inputs and labour and make more effective use of natural ecological processes (Mtakwa et al., 2019). In view of that, Conservation Agriculture can, therefore, be described as a set of soil management practices that minimize the disruption of the soil's structure, composition, and natural biodiversity. As described by (Mtakwa et al., 2019), conservation agriculture is in fact, a process that starts with reduced tillage, then conservation farming before conservation agriculture is attained when there is no more than 20% tilling of soil in order to preserve soil structure and aggregate stability, there is at least 30% organic cover throughout the year (so as to minimize heat fluxes in the soil, protect the soil from splash erosion that is normally severe at the onset of rains and smother weeds before cover crops establish). Finally, in addition to the above two pre-requisites, Conservation Agriculture as a process becomes complete when there is an established system of crop rotations that permit nutrient injection and cycling in the soil, aggregate stability enhancement and pest management. Conservation Agriculture aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water, and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource-efficient or resource effective agriculture.

Conservation Agriculture is a good example of climate-smart agriculture because crop production increases, the system is more resilient and there is more carbon stored in the soil (FAO, 2008). Conservation agriculture can, therefore, be described as a system of agronomic practices that includes reduced tillage, permanent organic soil cover by retaining crop residues or cover crops, and crop rotations (FAO, 2008). According to (FAO, 2012), Conservation Agriculture is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. It is characterized by three linked principles, namely: Continuous no- or minimal mechanical soil disturbance (i.e., reduced tillage and sowing or broadcasting of crop seeds, and direct placing of planting material in the soil; minimum soil disturbance from cultivation, harvest operation or farm traffic, in special cases limited strip or band seeding disturbing less than 25% of the soil surface (FAO, 2002, 2012); Maintenance of a permanent organic soil mulch cover, especially by crop residues, and cover crops.

These farming practices aim at resource-saving agricultural production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. This is the agricultural practice that enhances the sustained agricultural production and also contributes to environmental conservation services at the farm, landscape and provincial or national scale (Friedrich et al., 2009; Kassam et al., 2009). Table 1 lists common farming practices and helps to differentiate between Conservation Agriculture and Non-Conservation Agriculture practices.

Table 1: Conservation Agriculture and Non-Conservation Agriculture practices

Practices within the concept of CA	**Practices outside the concept of CA**
Sub-soiling/Chisel ploughing	Ploughing (Disc/mouldboard plough)
Ripping	Harrowing
Tied ridges	Ploughing/Harrowing
Vibro-flex cultivator	Roller tillers
Pitting	Ploughing/Harrowing
Direct seeding	Planting after plough
Crop rotation	Mono-cropping
Contours	Cultivation on sloping land
Cover crops	Incorporating green manure
Intercropping	Mono-cropping
Incorporation of mulch	Removing residues
Partial removal of crop residues	Crop residues burnt or used as fodder
Up-rooting and leaving weeds on the soil surface	Up-rooting weeds and removing them from the field
Agroforestry	Mono-cropping
Zero-grazing	Post-harvest grazing
Improved pasture	Crop residues as fodder

(Adapted from (Löfstrand, 2005))

2.2.1 Advantages of conservation agriculture

Conservation agriculture is generally a "win-win" situation for both farmers and the environment (FAO, 2001b; Knowler et al., 2001). The practice offers a powerful option for meeting future food demands while also contributing to sustainable agriculture and rural development (Tittonell, 2014). Conservation agriculture methods have been reported (Mtakwa et al., 2019; Ngwira et al., 2012; Shaxson & Barber, 2003; Thierfelder & Wall, 2009) to improve the efficiency of input, increase farm income, improve or sustain crop yields, and protect and revitalize soil, biodiversity and the natural resource base. Furthermore, Conservation Agriculture practices enhance soil organic matter (SOM) levels (Sapkota, 2012; West & Post, 2002), and nutrient availability by utilizing the previous crop residues or growing green manure/ cover crops and keeping these residues as a surface mulch rather than burning. Thus, arable land under conservation agriculture is more productive for much longer periods of time.

Land under no-till is not cleared before planting and involves less weeding, therefore it reduces the labour required (Chinseu et al., 2019; Mutenje et al., 2019; Wekesah et al., 2019). Pest control also reduces significantly following the establishment of permanent soil cover and crop rotations (Harrison et al., 2019; Stagnari et al., 2009). Farmers in Ghana reported a 22% savings in labour associated with maize production (Dalton et al., 2014). Similar reductions in labour requirements have been reported with no-till rice-wheat systems in South Asia and various conservation agriculture technologies in South America (Ares et al., 2015; Ceddia et al., 2014). Much of the reduced labour comes from the absence of tillage operations under conservation agriculture, which use up valuable labour days during the planting season.

Conservation agriculture requires significantly less water use due to increased infiltration and enhanced water holding capacity from crop residues left on the soil surface (Li et al., 2011). Mulches also protect the soil surface from extreme temperatures and greatly reduce surface evaporation, which is particularly important in tropical and sub-tropical climates (Adekalu et al., 2007). In Sub-Saharan Africa, as with other dryland regions, the benefits of conservation agriculture are most salient during drought years, when the risk of total crop failure is significantly reduced due to enhanced water use efficiency (Rockström et al., 2002).

Soil nutrient supplies and cycling are enhanced by the biochemical decomposition of organic crop residues at the soil surface that are also vital for feeding the soil microbes (Madejón et al., 2007). While much of the nitrogen needs of primary food crops can be achieved by planting nitrogen-fixing legume species, other plant essential nutrients often must be supplemented by additional chemical and/or organic fertilizer inputs. In general, soil fertility is built up over time under conservation agriculture, and fewer fertilizer amendments are required to achieve optimal yields over time (Sanginga & Woomer, 2009).

Insect pests and other disease-causing organisms are held in check by an abundant and diverse community of beneficial soil organisms (Sánchez-Moreno, 2016), including predatory wasps, spiders, nematodes, springtails, mites, and beneficial bacteria and fungi, among other species. Furthermore, the burrowing activity of earthworms and other fauna create tiny channels or pores in the soil that facilitate the exchange of water and gases and loosen the soil for enhanced root penetration (Reeleder et al., 2006; Ruiz et al., 2008). Conservation agriculture represents an environmentally-friendly set of technologies (IPCC, 2019). Because it uses resources more efficiently than conventional agriculture, these resources become available for other uses, including conserving them for future generations. The significant reduction in fossil fuel use under no-till agriculture results in fewer greenhouse gases being emitted into the atmosphere and cleaner air in general. Reduced applications of agrochemicals under conservation agriculture also significantly lessens pollution levels in air, soil, and water (Ethiopian Panel on Climate Change, 2015).

Conservation agriculture also has the benefit of being accessible to many small-scale farmers who need to obtain the highest possible yields with limited land area and inputs (Stevenson et al., 2014). It provides a number of advantages on global, regional, local and farm level. It provides a truly sustainable production system, not only conserving but also enhancing the natural resources and increasing the variety of soil biota, fauna and flora in agricultural production systems without sacrificing yields on high production levels (Mashavakure et al., 2019b, 2019a). As conservation agriculture depends on biological processes to work, it enhances the biodiversity in an agricultural production system on a micro- as well as macro-level (Tikhonovich & Provorov, 2011).

No-till fields act as a sink for CO_2 (Jastrow et al., 2007) and conservation farming applied on a global scale could provide a major contribution to control air pollution in general and global warming in particular. Farmers applying this practice could eventually be rewarded with carbon credits.

2.2.2 Constraints of conservation agriculture and some approaches to overcome them

Conservation agriculture has been successfully employed in sub-humid as well as humid climates, but there are still some constraints in semiarid environments that may hinder its immediate application (Vanlauwe et al., 2014). Typical of these constraints are: shortage of water limiting crop and residue production; insufficient residues produced by the economically or socially important crops and lack of knowledge of suitable cover crops; sale or preferential use of crop residues for fodder, fuel and building materials; inability to control livestock grazing, especially in areas where communal grazing is traditional (tenant farmers are often obliged to allow the landowner's cattle to graze the residues after harvest); inability to control residue consumption by termites; insufficient money or credit to purchase appropriate equipment and supplies; and lack of knowledge of conservation agriculture by extension and research staff (Fisher et al., 2018; Friedrich & Kassam, 2009; Grabowski & Kerr, 2014; Ngwira et al., 2013).

Several approaches have been explored and are being tested to overcome these constraints. In situations where crop residues are preferentially used as fodder, additional new sources of fodder may be produced, provided they can be protected from grazing by, for example, live fences (Herrero et al., 2010; Valbuena et al., 2012). Certain crop sequences are less suited to direct sowing into crop residues because of the likelihood that weed, pest or disease problems will become intensified by being transmitted from one crop to the next (Govaerts et al., 2006).

Weed problems may also be caused by volunteer germination of the previous crop; for example, sunflower volunteers can be particularly difficult to eradicate (Shrestha et al., 2002). To avoid such problems, appropriate crop rotations, acceptable to the farmers, must be selected (Mhlanga et al., 2016). In environments where there are many constraints to the introduction of conservation agriculture, a pragmatic, phased approach may be the most feasible, in which individual constraints are progressively overcome until an appropriate system of conservation agriculture can be fully implemented (Grabowski & Kerr, 2014). This may require the planned introduction of measures such as improved grass species and fodder trees, hay and silage production, live fences, stall-fed livestock, improved crop rotations with cover crops, formation of farmers' associations, credit supply and local or international training visits for farmers, extension and research staff (Dixon et al., 2001).

The introduction of conservation agriculture is unlikely to be immediately successful on seriously degraded soils with surface crusts, compacted layers, low fertility or severe weed infestations unless these problems are first overcome by appropriate remedial actions (Lal & Stewart, 2019). Hard setting soils may not be immediately suitable for conservation agriculture because of the difficulties of overcoming soil compaction problems and maintaining good soil porosity within the topsoil and subsoil. Consequently, crop rooting is frequently restricted to shallow depths. In this case, deep tillage followed by the establishment of cover crops prior to introducing conservation agriculture, and then the adoption of crop rotations that produce large quantities of residues, will progressively improve the physical condition of these soils and make conservation agriculture possible (Watt et al., 2006).

Conservation agriculture is less likely to be successful in poorly drained soils because the added residues will intensify anaerobic conditions, in which toxic substances harmful to crop growth may be produced (Shaxson & Barber, 2003). The cost of no-till planters and seed drills needed for direct sowing may be a major constraint for mechanized farmers. Unless it is possible to modify their existing seed drills and planters. For small farmers, hand tools and animal-drawn equipment exist, and local blacksmiths can often adopt them, provided they have access to information and samples (Mkomwa et al., 2011).

2.3 Status of conservation agriculture in Sub-Saharan Africa

Conservation agriculture is being practiced in several countries as traditional soil and water conservation practices by specific communities or at the pilot project scale throughout Africa. Twenty years ago, the situation was different as described in the comprehensive historical review of no-tillage cultivation of crops (Derpsch & Friedrich, 2010; Farooq & Siddique, 2015). The review observes that the earliest research on no-tillage in Africa was carried out in the late sixties in Ghana. Research work at the IITA (International Institute of Tropical Agriculture) in Ibadan, Nigeria started in 1970 (Lal & Stewart, 2019). The review also recognizes similar studies that were initiated in other African countries including Liberia by Lal and Dinkins, Ivory Coast by Roose and Senegal by Nicou and Chopart.

Despite the wealth of research information on no-tillage and mulch farming in Africa, the technology had not spread to a great extent among farmers by the year 2000 (Kassam et al., 2015). There was only little information available on the development of no-tillage farming in Africa. A study on the potential use of no-tillage in Africa conducted by GTZ (Derpsch & Friedrich, 2009), indicated, that the technology was already being used to some extent in the following countries: Angola, Benin, Ghana, Ivory Coast, Kenya, Mozambique, Niger, South Africa, Tanzania, Zambia and Zimbabwe. In most countries in Southeast Africa some work on conservation tillage practices (either at research stations or on farms) was being done and no-tillage was practiced successfully in larger farms (Mazvimavi & Twomlow, 2009). The most common crops that were used in no-tillage are maize, sorghum, wheat, and cotton.

In mechanized farms, no-tillage seeding machines were often imported from Brazil, New Zealand or from the USA, but in Zimbabwe there was also a local production (Johansen et al., 2012). No-tillage seeding equipment for small farms was manufactured in South Africa for experimental purposes and in some cases imported from Brazil. On the other hand, according to the Conservation Tillage Handbook in Zimbabwe (Swanepoel et al., 2018), many farmers had modified their planters to enable them to plant row crops directly through crop residues with no previous tillage operation. Although experimentation with zero tillage in many cases began with irrigated crops, it is assumed that under dryland conditions the potential benefits of zero tillage are the greatest (Shetto & Owenya, 2007). It should also be mentioned, that permanent zero tillage is practiced only in regions with higher rainfall patterns or when irrigation is available. Minimum tillage is used widely and is the most common form of soil preparation in small farms (1 – 2 ha) (Kahimba et al., 2014; Kaweesa et al., 2018).

Ten years after the historic review, (Derpsch & Friedrich, 2009), reported that no-tillage in Africa was in a state of intensive promotion for a decade. Many African countries, particularly in Southern and Eastern Africa had been exposed to no-tillage systems and conservation agriculture, and some of them had included this into their government policies. A number of emergency rehabilitation projects (Fowler & Rockstrom, 2001), promoted conservation agriculture in several countries, such as Zambia, Zimbabwe, and Swaziland. Conservation agriculture activities and promotion programmes existed especially in Kenya, Tanzania, Zambia, Zimbabwe, Lesotho, Swaziland, Mozambique and Malawi and Conservation Agriculture had also been incorporated into the regional agricultural policies by NEPAD (New Partnership for Africa's Development) and more recently by AGRA (Alliance for a Green Revolution in Africa).

The area in ha is still small since most of the promotion has been among small farmers, but there is a steadily growing movement in the region already far more than 100,000 small scale farmers, with an adoption area in Kenya and Tanzania of about 20,000 ha (Kassam et al., 2019). The simultaneous application of the three principles of conservation agriculture started recently and has emerged in several places, most notably in South Africa, Zimbabwe, Zambia, Kenya, and Tanzania (Thierfelder, et al., 2013). Conservation agriculture has spread rapidly in Ghana from a handful of farmers in 1996 to 350,000 by 2002 through Monsanto and GTZ (Kaumbutho & Kienzle, 2007). Malawi is beginning to have renewed interest and has currently 47,000 ha under "some form" of conservation agriculture involving 5,407 groups of farmers. Out of the 47,000 ha at least 1000 ha can truly be said to be under Conservation Agriculture (Bunderson et al., 2017).

In Tanzania, conservation agriculture is being promoted especially in Arusha region through indigenous and non-indigenous technologies, as a combination of crop and crop-livestock production practices that make land more productive even as it improves the resilience of natural resources (Kahimba et al., 2014; Owenya et al., 2011). A study on Conservation Agriculture in Karatu and Babati districts in Tanzania showed that the two districts had varied experiences with regard to the introduction of Conservation Agriculture through both indigenous and nonindigenous technologies (Lugandu, 2013). Although both originated from concerns about the impact of conventional tillage practices on land degradation. Both districts commenced with subsoiling in the latter part of the 1990s. In Karatu this was followed by the introduction of cover crops while Babati placed more emphasis on reduced tillage systems. Key stakeholders have played a major role in driving these initiatives forward: Selian Agricultural Research Institute (SARI) and Tanzania Farmers Service Centre (TFSC) in Karatu, and the Land Management Programme (LAMP) together with Soil Conservation and Agroforestry Programme in Arusha (SCAPA) (Owenya et al., 2011).

2.4 Conservation agriculture and food production

The central reason for food shortage in the Sub-Sahara region is insufficient food production which has become a major problem in most developing countries (Barrett, 2010). According to the Africa human development report (P. Conceição, 2012), the region has nearly 218 million people who are food insecure and undernourished. The report further clarifies that food security is a core component of the human development and capability paradigm. Thus, enhancing food availability and entitlements is a robust way to sustainable human development (Pedro Conceição et al., 2016). Countries like Burkina Faso, Mali, Niger, Malawi, Kenya, and Tanzania have already been adversely affected by climate change (IPCC, 2014; Mmbando et al., 2015). While climate is increasingly impacting the production, the population growth has been increasing rapidly, and thus, food production has not been kept up with population growth (Edwards, 2018; Godfray et al., 2010).

To improve food security, social welfare and economic development, Mkonda and He (2017) suggest that there is need to be more innovative in the production systems and more preferably the dissemination of research finding on crops, fertilization and possible irrigation (Mkonda & He, 2017). Numerous studies have been conducted to compare the yields of conservation agriculture systems to those of conventional farming systems. The general pattern from this research is that yields increase in both the short- and long-term as a result of conservation agriculture. Recent reviews of research in Latin America, Africa, and Asia have concluded that conservation agriculture yields are approximately 20-120% higher than those in conventional agriculture (Derpsch et al., 2010; Kassam et al., 2009). In Africa, numerous studies have also documented yield increases associated with a shift to conservation agriculture practices across a range of geographies and crops. For instance: (Kaumbutho & Kienzle, 2007) found that in the Laikipia district in Kenya yields in maize, wheat, potato, and bean were 50-200% higher in CA than in conventional systems; (Boahen et al., 2007) reported that maize yields in Ghana were up to three times higher with conservation agriculture than in traditional slash-and-burn systems; According to (Shetto & Owenya, 2007), yields increased by 93-360% in maize and sunflower conservation agriculture systems in Tanzania following adoption of conservation tillage (ripping) and a mucuna cover crop; In Uganda, conventional systems have a grain yield of about 2,500 kg/ha, but yields increase to 3,000-3,100 kg/ha under different conservation agriculture methods (Nyende et al., 2007); (FAO, 2013) found significant yield increases in Zimbabwe across several crops, including maize, sorghum, millet, cowpea, and soybean; When examining conservation agriculture yields in Malawi, (Mloza-Banda & Nanthambwe, 2010) found that maize grain yields from conservation agriculture were between 294% and 477% higher than yields in traditional systems in 2000/2001 and 394% to 609% higher in 2001/2002 across six different Agricultural Development Divisions; In Zambia, yields on farms using conservation agriculture practices doubled in maize plots and were 60% higher for cotton, as compared to conventional ploughing systems (Haggblade, S & Tembo, G, 2003); Based on a meta-analysis of 94 peer-reviewed publications from all regions of sub-Saharan Africa, (Sileshi et al., 2008) determined that maize yields increased significantly through the use of rotations or intercropping with woody or herbaceous legumes (which are commonly a component of African conservation agriculture). Yield increases averaged 1.6 t/ha for coppiced woody legumes, 1.3 t/ha for non-coppiced woody legumes, and 0.8 t/ha for herbaceous green manure legumes.

While yield increases can be substantial, they depend on local conditions. There can also be considerable year-to-year variation in the yield benefits provided by conservation agriculture, depending on the weather. For example, in commercial maize systems in Zimbabwe, yield benefits were recorded in normal and dry years, but not in wet years (Giller et al., 2009). There are several mechanisms by which conservation agriculture can improve yields in sub-Saharan Africa, and these often work in synergy. Mulching and residue management can increase soil fertility and nutrient availability to plants, which is one of the surest ways to boost production of nutrient-hungry crops such as maize. Improved water availability throughout the cropping cycle is another key mechanism (Qin et al., 2015). Also important in seasonally dry climates is the ability to seed crops immediately after the rains begin, thus accelerating the crop growth cycle and maximizing utilization of rainfall during a short rainy season (FAO, 2010). Complementary practices suggested by (Milder et al., 2011) including the use of context-appropriate high-yielding seeds, appropriate seed spacing and densities, use of inorganic and/or organic fertilizers, and improved pest management practices can increase the yield gains associated with improved soil, residue, and water management

2.5 Conservation agriculture and biodiversity conservation

Conservation agriculture tends to have three broad categories of impacts on the conservation of biodiversity and ecosystem services, all of which are generally positive. The impacts are well elaborated by (Milder et al., 2011); First, conservation agriculture has direct impacts on the plot- and farm-scale ecosystem services, which are deliberately managed as part of conservation agriculture practice. Second, conservation agriculture has indirect effects on additional ecosystem services as well as associated biodiversity within and around cultivated areas at the farm and community scale. Third, conservation agriculture has indirect effects on biodiversity and ecosystem conservation at the community, landscape, and even larger scales.

Diversification of agricultural landscapes through the use of crop rotations, cover crops, intercropping, agroforestry, and rotational fallows is likely to increase ecosystem services provided by non-domesticated species (insects, birds, bats, etc.), including pollination and pest control (Wezel et al., 2015). These relationships have not been specifically studied in relation to Conservation Agriculture management. However, based on research elsewhere in Africa, Europe, and the Americas, it is reasonable to hypothesize that increased landscape diversity would almost always improve pollination services, and frequently, but not always, help protect crops from pests and predators (Bommarco et al., 2013).

Agrodiversity, as described in (Tscharntke et al., 2012), is the many ways in which farmers use the natural diversity of the environment for production, not only including their choice of crops but also their management of land, water, and biota as a whole. Agrodiversity has also been described as an interaction between management practices, biophysical resources, and plants (Chikowo, 2011). The four principal elements of agro diversity include biophysical diversity, management diversity, agrobiodiversity, and organizational diversity. The elements overlap but each of them constitutes distinctive parts that have their own rationale. The practice of conservation agriculture promotes agrodiversity.

In conservation agriculture systems, the sequences and rotations of crops encourage agrobiodiversity as each crop will attract different overlapping spectra of microorganisms (Tikhonovich & Provorov, 2011). The optimization of populations, range of species and effects of the soil-inhabiting biota is encouraged by the recycling of crop residues and other organic matter which provides the substrate for their metabolism. Rotations of crops inhibit the build-up of weeds (Mhlanga et al., 2016), insect pests and pathogens by interrupting their life cycles (Harrison et al., 2019), making them more vulnerable to natural predator species, and contributing development-inhibiting allelochemicals (Caamal-Maldonado et al., 2001). The same crop mixtures, sequences, and rotations provide above-ground mixed habitats for insects, mammals, and birds (Kassam et al., 2009).

Soil macro-organisms or macro-fauna are the soil organisms that are visible to the naked eye (>2 mm diameter). That include the invertebrates that live in, feed in or upon the soil, the surface litter and their components viz snails, earthworms and soil arthropods like ants, termites, millipedes, centipedes, pill bugs and other crustaceans, caterpillars, cicadas, ant-lions, beetle larvae and adults, fly and wasp larvae, earwigs, silverfishes, spiders, scorpions, crickets and cockroaches (Ruiz et al., 2008). These soil macro-organisms are an integral part of agricultural ecosystems, most of them consume decaying plant material and organic debris, but some for-example centipedes and spiders prey on other soil animals.

The presence of a range of a diverse community of soil organisms is essential for the maintenance of fertile soils and productive lands for agriculture (Wardle, 2002). Soil organisms are responsible for a range of ecological functions and ecosystem services including: nutrient cycling and nitrogen fixation, control of pest and diseases, organic matter decomposition and carbon sequestration, maintenance of a good soil structure for plant growth and rainwater infiltration, as well as detoxification of contaminants (Doran & Zeiss, 2000; Jiménez, 2001; Lavelle & Spain, 2001). Healthy soil is home to a great diversity of soil macro-organisms. A diverse and abundant community of soil organisms makes for a healthy, resilient and productive soil. These organisms provide ecosystem services by affecting the physical, chemical and biological aspects of soil health.

Disturbance associated with tillage has been shown to alter the structure of soil-associated food-webs as well as the composition and diversity of soil macro-organism communities (Lavelle & Spain, 2001). Above-ground manipulations, such as ground cover vegetation or residue management, also have potentially important effects on soil macro-organisms, manifested largely through alteration of microclimatic conditions and resource availability (Adekalu et al., 2007). Tillage, according to research (Miura et al., 2008; Sapkota, 2012), can either enhance or reduce the diversity of soil-associated invertebrates depending on its intensity and frequency.

Conservation agriculture practices, such as reduced tillage, cover crops, and fertilization, are often associated with greater microbial biomass and activity that are linked to improvements in soil quality and health (Mbuthia et al., 2015). Soil quality is the general term used to refer to “the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health” (Doran & Zeiss, 2000). Microorganisms are crucial in the cycling of nutrients through biochemical reactions in order to unlock essential elements that are taken up by other organisms and locked in an unusable form by others (Habig et al., 2015). Therefore, the microbial ecology of the soil is extremely important to the biogeochemical cycling of nutrients that is vital to life on our planet.

Soil provides the largest reservoir of biodiversity on Earth and sustains all other forms of terrestrial diversity while providing many ecosystem services (Hinsinger et al., 2009). Soils are important habitats for Prokaryotes and the diverse Eukaryotes, which comprise fungi among soil microorganisms, as well as large variety of invertebrates (from protozoa and nematodes to mites, collembola, insects, and earthworms). The diversity of Prokaryotes in soil has been estimated to be about three times more than in all other environmental compartments of the Earth’s ecosystems combined (Crawford et al., 2005; Curtis & Sloan, 2005). Besides species richness, species abundances are also remarkable in soils (Watt et al., 2006; Young & Crawford, 2004). Microorganisms are found in extremely high numbers in soil habitats with bacteria reaching numbers of 10^6–10^9 per gram of soil (Habig et al., 2015). Other soil microorganisms include viruses, fungi, nematodes, algae, and protozoa. For this reason, soils are described as complex assemblages of extremely diverse habitats, which certainly explain why they harbour such a diversity of organisms (Hinsinger et al., 2009).

From numerous site-specific research, it is well known that soil bacterial diversity is immense (Dunbar et al., 2002; Tringe et al., 2005) and that the composition and diversity of soil bacterial communities can be influenced by a wide range of biotic and abiotic factors (Fierer & Jackson, 2006; Staley & Reysenbach, 2002). However, the soil pH has dramatic importance for below-ground life. One of the most striking pieces of evidence is shown by recent biogeographical studies. For instance, the (Fierer & Jackson, 2006) study which investigated a data set of 98 soils sampled across the Americas. This study showed that temperature, rainfall, and latitude had virtually no effect on the diversity and richness of soil microbial communities, whilst soil pH had a major effect, by far the largest amongst the investigated parameters. Bacterial diversity was highest in neutral soils and minimal in acidic soils. Interestingly, through their physiological functions, plant roots and soil microbes are however capable of considerably altering soil pH relative to the bulk soil. Rhizosphere pH has been reported to be up to 1–2 pH units below or above bulk soil pH (Hinsinger et al., 2009). A primary function of below-ground organisms which can substantially impact soil pH is respiration and the subsequent increase in the partial pressure of carbon dioxide (pCO_2). Because of respiration, bulk soil pCO2 is well-known to be much (ten to hundred-fold) higher than that of the atmosphere (Hinsinger et al., 2009). Therefore, soil pH, as many other chemical and physical properties, can substantially vary in space and time. In this study, soil pH measurements taken just before collecting the soil sample for this analysis, showed that this soil was slightly acidic in all the plots with a mean pH of 5.650. Comparing between the conservation and conventional tillage plots in this experiment, there was no significant difference in the diversity and abundance of microbes. However, for the plots that had countable numbers, some had lower than the average expected number of bacteria cells per gram of soil viz animal ripping control, animal ripping grass, hand basin grass, hand ridges grass, tractor plough control, tractor ripping control and tractor ripping rice husks. These treatments are mixed with both conservation and conventional tillage.

The composition and activity of soil microbial populations are responsible for all the major processes in the soil, such as breakdown of contaminants and nutrient recycling, which contributes to soil fertility and quality (Anderson, 2003). In an agricultural production system where mineral fertilizers can provide most nutrient inputs, the effects of decomposition and mineralization almost seem irrelevant, but knowledge about the dynamics between soil microbial communities and the ecosystem might become more significant as conservation agriculture develops into a system that is less dependent on mineral fertilizers, biocides, and fossil fuels (Philippot et al., 2013).

Besides their role in biodiversity, soils are even more remarkable from a functional perspective, in sustaining all other forms of terrestrial diversity and providing many ecosystem services. Therefore, by applying the correct agricultural practices as prescribed for conservation agriculture, the soil ecosystem is granted the opportunity to nurture natural biological control measures during the build-up of soil cover.

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2.6 Conservation agriculture and soil health

An integral part of conservation agriculture is the management of soil fertility and hydrological cycling, two key ecosystem services that support agricultural productivity. Considerable research has been conducted on these potential benefits in sub-Saharan Africa and elsewhere. In terms of soil fertility, the improved soil structure resulting from conservation agriculture enhances aeration and other conditions required for efficient nutrient cycling. Soil organic matter has been found to increase significantly over time in conservation agriculture systems, due primarily to the introduction of additional organic matter as crop residues or mulch and to the reduction or elimination of tillage, which tends to speed the oxidation of soil organic matter (Hobbs et al., 2007; Kassam et al., 2009). Zero tillage systems are also associated with increased levels of available phosphorus in the upper soil layer (e.g., 0-5 cm), apparently due largely to the role of biological processes in phosphorus cycling (Verhulst et al., 2010).

The key feature of a sustainable soil ecosystem is the biotic actions on organic matter in suitably porous soil (Kladivko, 2001; Lavelle & Spain, 2001). This means that, under conservation agriculture, soils become potentially self-sustainable. In conservation agriculture systems with the above attributes, there are many similarities to resilient 'forest floor' conditions (Blank, 2008). Organic materials are added both as leaf and stem residues from above the surface and as root residues beneath the surface where the soil biota are active and carbon is accumulated in the soil; Carbon, plant nutrients and water are recycled; Rainwater enters the soil complex readily, since rates of infiltration (maintained by surface protection and varied soil porosity) usually exceed the rates of rainfall.

Soil organic matter is neither just a provider of plant nutrients nor just an absorber of water. The combined living and non-living fractions together form a key part of the dynamics of soil formation, resilience and self-sustainability of conservation agriculture systems (Lavelle & Spain, 2001). In the functioning of soil as a rooting environment, the integrated effects of the physical, chemical and hydrological components of soil productive capacity are effectively 'activated' by the fourth, the biological component. This variously provides metabolic functions, acting on the non-living organic materials (Coleman et al., 2004; Doran & Zeiss, 2000; Lavelle & Spain, 2001; Uphoff et al., 2006) to:- retain potential plant-nutrient ions within their own cells, with liberation on their death, acting as one form of slow-release mechanism; mycorrhizae and rhizobia, as well as free-living Nitrogen fixing bacteria, make nutrients available to plants in symbiotic arrangements; break down and transform the complex molecules of varied dead organic matter into different substances, both labile and resistant, according to the composition of the substrate; leave behind transformed materials with differing degrees of resistance to subsequent breakdown by biotic process of other soil organisms.

Over the long term, this leaves some residues less changed than others, providing long-lasting and slowly released remnant reserves of the nutrient and carbonaceous materials of which they were composed (Roy et al., 2006). Produce organic acids which, by leaching, contribute to soil formation from the surface downwards by acting to break down mineral particles as part of the soil 'weathering' process. Organic acids also help with transporting lime into the soil profile and mobilizing nutrients like phosphates (Kisinyo et al., 2014). This provides organic molecules as transformation products that contribute markedly to soil's CEC; this also augments the soil's buffering capacity to pH changes and to excesses or deficiencies of nutrient ions available to plants (Lesschen et al., 2007). It also provides humic gums which, together with fungal hyphae and clay bonds, make for different sizes of rough-surfaced aggregates of individual soil particles that in turn provide the permeability of the soil in a broad distribution of pore sizes. Finally, it increases the burrowing activities of meso-organisms such as earthworms, and of roots (leaving tubes after they have died and been decomposed) (Reeleder et al., 2006).

The soil capacity to favour root growth and water transmission are maintained through the activity of soil organisms sufficiently provisioned with organic matter, water and nutrients (Young & Crawford, 2004). A consequence of their activity is soil aggregation interspersed with voids (pores), depending on organisms' production of roots, exudates, gums, hyphae and on their proliferative burrowing and distributive activities. Multiple attributes of organic matter in soil – dynamized by the soil biota – therefore making it a key factor for improving and maintaining yields (of plants and of water) (Haddaway et al., 2017). Management actions that increase and /or optimize organic matter content of soils tend to be beneficial; those that result in depletion of organic matter content tend to be detrimental.

The evidence regarding the effects of Conservation Agriculture on nitrogen availability is somewhat mixed. Nitrogen availability may be lower due to initial immobilization caused by crop residues on the surface (Giller et al., 2009; Verhulst et al., 2010) and higher leaching of inorganic nitrogen (Reicosky & Saxton, 2007). Thus, nitrogen fertilizers may be desirable in young Conservation Agriculture systems. Over time, however, the need for fertilizer inputs is generally reduced. In established Conservation Agriculture systems, most nutrients are concentrated and maintained in the top 10 cm of the soil, where they are readily accessible to plants (Kassam et al., 2009). Soil fertility also benefits from reduced rates of erosion in Conservation agriculture systems (Reicosky & Saxton, 2007). On the other hand, legumes in conservation agriculture rotations provide increased in situ availability of nitrogen, thus diminishing the need for large amounts of applied nitrogenous fertilizers (Boddey et al., 2009). Also, there is increasing evidence of a significant amount of 'liquid carbon' being deposited into the soil through root exudation into the rhizosphere (Hinsinger et al., 2009).

Tillage has long been used by farmers to loosen soil, make a seedbed and control weeds. But not all outcomes are positive, especially when considered over long timescales. Wheels, implements and even feet can compact soil. As explained by (Kassam et al., 2009), too-frequent (and/or too severe) tillage results in disruption of the aggregates making up a soil's biologically induced architecture. Since the sustainability of a soil's productive capacity depends on the influence of the soil biota on soil crumb/ aggregate re-formation, the soil aerating effects of undue tillage can accelerate the rate of biotic activity and the consequent more-rapid oxidation of their substrate organic matter (Anderson, 2003). If the mean rate of soil's physical degradation exceeds the mean rate of its recuperation due to the soil biota, its penetrability by water, roots and respiration gases diminishes, productivity declines, and runoff and erosion ensue. The soils which are most vulnerable to tillage-stimulated rapid loss of soil organic matter are those of coarse texture and where the clay fraction is dominated by low-activity clays. Such soils (e.g., ferralsols, cambisols) are widely distributed in the tropics and subtropics, and total over 750 million ha (E. L. D. Initiative & UNEP, 2015).

The relationship between components of Conservation Agriculture and desired soil conditions are listed in Table 2 (T. Friedrich et al., 2009).

Table 2: Effects of CA components when applied together

CA component → To achieve ↓	Mulch cover (crop residues, cover-crops, green manures)	No tillage (minimal or no soil disturbance)	Legumes (as crops for fixing nitrogen and supplying plant nutrients)	Crop rotation (for several beneficial purposes)
Simulate 'forest floor' conditions	√	√		
Reduce evaporative loss of moisture from soil surface	√			
Reduce evaporative loss from upper soil layers	√	√		
Minimize oxidation of soil organic matter, CO_2 loss		√		
Minimize compaction by intense rainfall, passage of feet and machinery	√			
Minimize temperature fluctuations at soil surface	√			
Maintain supply of organic matter as substrate for soil biota	√			
Increase and maintain nitrogen levels in root-zone	√	√	√	√
Increase CEC of root-zone	√	√	√	√
Maximize rain infiltration; minimize runoff	√	√		
Minimize soil loss in runoff or wind	√	√		
Maintain natural layering of soil horizons by actions of soil biota	√	√		
Minimize weeds	√	√		√
Increase rate of biomass production	√	√	√	√
Speed soil porosity recuperation by soil biota	√	√	√	√
Reduce labour input		√		
Reduce fuel-energy input		√		
Recycle nutrients	√	√	√	√
Reduce pests and diseases				√
Rebuild damaged soil conditions and dynamics	√	√	√	√

Source: Friedrich et al., 2009

Conservation agriculture influences soil physical properties as well as chemical and biological properties (Verhulst et al., 2010). Historically, soil was mainly considered as a medium to support crop growth, but it is now realized that they also play vital roles in ecosystem functioning, water and nutrient cycling, and food production (Wander et al., 2002). Conservation agriculture has potential to improve water infiltration and reduce erosion, improve soil aggregation, reduce soil compaction, increase surface soil organic matter and soil carbon content, and regulate soil temperature. These influences to soil health have been highlighted by various reviews (Govaerts et al., 2009; Hobbs, 2007; Kassam et al., 2009; Wall, 2007).

2.6.1 Relative soil nutrient status

Soil health in this study is defined in terms of soil nutrient content. Soil health conditions are classified in four levels namely; Deficiency range, Critical range, Sufficiency range and Toxicity range (Arshad & Martin, 2002). The levels are described by FAO plant nutrient and soil amendment guidelines (Roy et al., 2006) as follows: *Deficiency range* is the level when an essential element is not taken up by the plant in sufficient amounts. As a result, yield will be limited by the element which is deficient. Slight to moderate deficiencies do not always result in visual deficiency symptoms, but distinct visual symptoms appear in severe cases. *Critical range* is that range of nutrient concentration above which we are reasonably confident the crop is amply supplied and below which we are reasonably confident the crop is deficient. Below the critical range of nutrients, an addition of the essential element will trigger an increase in yield. Above the critical range, the levels of essential nutrients are considered sufficient. *Sufficiency range* is the range within which, additions of the essential nutrient will not result in any increase in yield. However, uptake of the nutrient may continue. Thus, the concentration of that essential nutrient in plant tissue will also increase. We refer to the uptake of an essential nutrient within the sufficiency range as luxury consumption. *Toxicity range* - toxicities occur when an essential (or nonessential) element is taken up in great enough quantities to actually reduce plant growth. As a result, toxicities can severely limit yield.

The minimum required nutrient levels in a healthy soil is the critical range. At this level, crops will grow and produce optimally if all other factors are held constant. The critical range for most of soil chemical properties are shown in Table 3.

Table 3: Critical range values for soil chemical properties

Parameter	**Units**	C**ritical level**
Soil pH (1:2.5)	(in H2O)	5.5 - 7
EC	S/cm	4
DTPA Extractable Cu	mg kg^{-1}	0.2-2
DTPA Extractable Zn	mg kg^{-1}	1
DTPA Extractable Mn	mg kg^{-1}	2.5-5
DTPA Extractable Fe	mg kg^{-1}	4.5 - 10.0
TN-Kjeld	(%)	0.2 - 0.4
Organic C-BlkW	(%)	4.0-10
Extractable P (Bray-1)	mg kg^{-1}	10.0-15
Cation exchange capacity (CEC)	cmol kg^{-1}	15 -25
Exchangeable Ca2+	cmol kg^{-1}	5.1 - 10.0
Exchangeable Mg2+	cmol kg^{-1}	1.1-3.0
Exchangeable Na+	cmol kg^{-1}	N/A
Exchangeable K+	cmol kg^{-1}	0.2-0.4

Source (Landon, 2014)

The study focused on five chemical parameters namely; Nitrogen, Phosphorous, potassium, organic carbon and pH. This section will introduce each briefly.

Nitrogen is so vital because it is a major component of chlorophyll molecule, gives plants their green colour, and is the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide (i.e., photosynthesis). It is also a major component of amino acids, the building blocks of proteins (Sawyer, 2008). Without proteins, plants wither and die. Nitrogen is found in healthy soils, and give plants the energy to grow, and produce fruit or vegetables. For plants nitrogen is the nutrient in most demand, but too much is as bad as too little. Excess of nitrogen or an imbalance of nitrogen compared with other nutrients can make plants more prone to pest and disease attack (Kahl, 2004).

Tillage practices can influence content and dynamics of soil phosphorous (Papini et al., 2007). Unlike carbon and nitrogen, phosphorous does not readily undergo oxidation – reduction reactions in the common processes of organic matter decomposition, but it occupies a central position in organic matter decomposition (Zibilske et al., 2002). Furthermore, Phosphorous readily precipitates with metal ions like Fe, Al and Ca, producing sparingly soluble compounds (Papini et al., 2007). Organic phosphorous, immobilized in plant and microbe tissues, constitutes a more labile phosphorous form and is mineralized as organic matter decomposes. For these reasons soil phosphorous accumulation rates may be different than those seen for carbon and nitrogen and it is important to understand the influence of conservation tillage systems on soil phosphorous dynamics to ensure adequate phosphorous nutrition to crops.

Soil organic carbon is an essential macronutrient required in large quantities for plants development. It improves the physical properties of the soil, increases the cation exchange capacity (CEC) and the water-holding capacity. It also releases nutrients for plant growth, promotes the structure, biological and physical health of soil, and is a buffer against strong changes in pH (FAO, 2019). It is widely accepted that the organic carbon content of the soil is a major factor in its overall health.

2.7 Conservation agriculture and soil moisture conservation

Conservation agriculture has also been found to have beneficial effects on water management and water use efficiency. With an increase in soil organic matter and root density under conservation agriculture, water infiltration and water holding capacity are improved, making water more available throughout the farming cycle (Reicosky & Saxton, 2007). For each percent increase in soil organic matter, an additional 150 m^3/ha of water can be stored in the soil (Friedrich, 2008). Surface mulches and improved soil pore structure also increase infiltration and absorption capacity, while reducing evaporation. These benefits help reduce the risk of erosion and flooding during heavy rains, contribute to aquifer recharge, and make more water available to crops (Derpsch, 2008; Hobbs, 2007; Verhulst et al., 2010). Taken together, these characteristics increase crops' resistance to drought and tend to reduce yield variations between dry and wet years relative to conventional farming practice.

2.8 Conservation agriculture and carbon sequestration

Climate change will affect agriculture through higher temperatures, greater crop water demand, more variable rainfall and extreme climate events such as heat waves, floods and droughts (Friedrich, 2008). Marginal areas, where low yields and poverty go hand in hand, may become even less-suited for agriculture as a result of land degradation through deforestation, wind and water erosion, repetitive tillage and overgrazing (IPCC, 2019). Many impact studies point to severe crop yield reductions in the next decades without strong adaptation measures, particularly in Sub-Saharan Africa and South Asia, where rural households are highly dependent on agriculture and farming systems are highly sensitive to temperature increases and volatile climate (Tittonell & Giller, 2013).

While agriculture is the sector most vulnerable to climate change, it is also a major cause, directly accounting for about 13 percent of greenhouse gas emissions, or approximately 30 percent when considering land-use change, including deforestation driven by agricultural expansion for food, fibre and fuel (IPCC 2007),and Figure 1 and Figure 2. And yet, agriculture can be a part of the solution: helping people to feed themselves and adapt to changing conditions while mitigating climate change. Climate projections for Africa (IPCC 2007) include a likely average temperature increase of 1.5 to 4°C in this century, higher than the global average. Assuming even moderate temperature rises, warming and drying could reduce crop yields by 10–20 percent by 2050 in Africa (Jones & Thornton, 2009). This overall projection translates into much more severe losses in certain places and does not account for extreme events: pests and diseases; droughts, heat stress and floods.

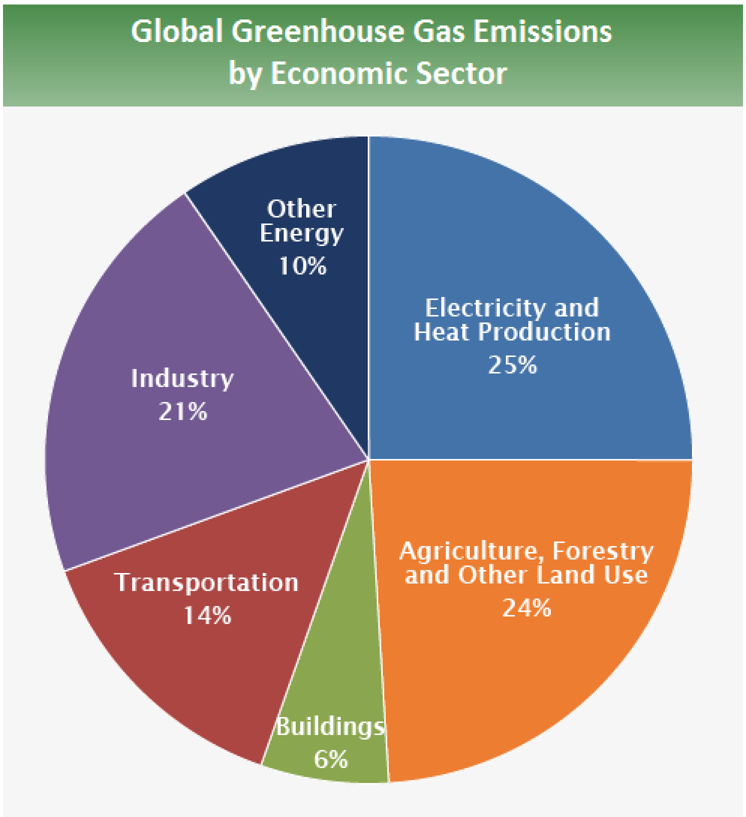

Figure 1: Greenhouse Gas Emissions by Sector
Source: IPCC, 2007

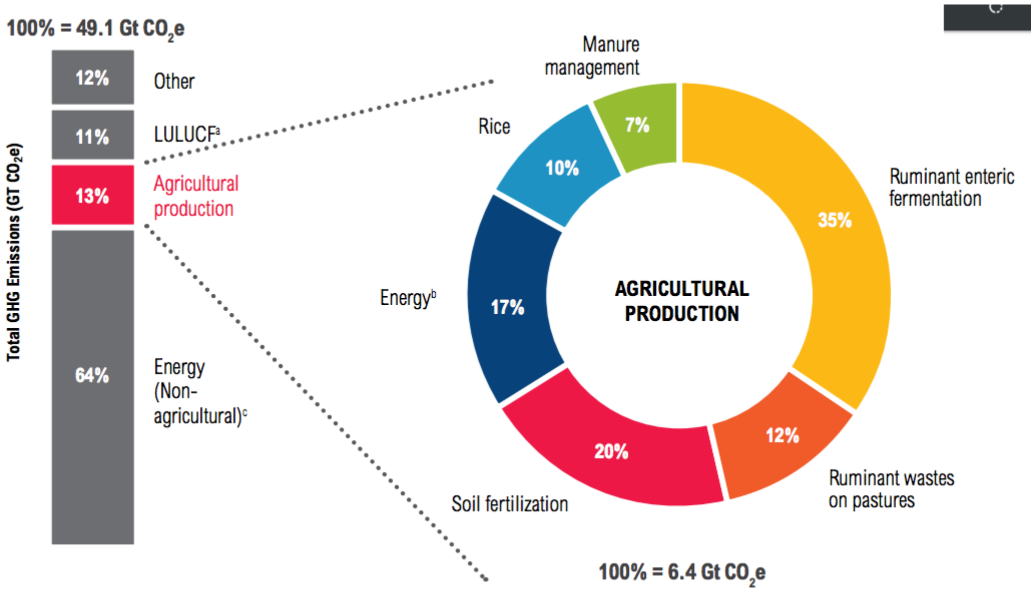

Figure 2: Emissions in the Agriculture Sector

Source: IPCC, 2007

Carbon sequestration is the process by which atmospheric carbon dioxide is taken up by plants through photosynthesis and stored as carbon in biomass and soils (Boddey et al., 2009; Reicosky & Saxton, 2007). Carbon sequestration will not only stabilize climate but will also make agricultural production more sustainable, increase the overall resilience of agro-ecosystems and maintain the ecosystem services that are supported by soils (Jastrow et al., 2007). It is estimated that the global stock of soil organic C (SOC) is in the range 684–724 Pg to a depth of 30 cm and 1462–1548 Pg to a depth of 1 m (Batjes, 2014). Thus, the quantity of SOC in the 0–30 cm layer is about twice the amount of C in atmospheric carbon dioxide (CO2) and three times that in global above-ground vegetation. It was estimated in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) that the annual release of CO2 from deforestation (coming from both vegetation and soil) is currently some 25% of that from fossil fuel burning (IPCC, 2007).

A study in Brazil (Machado et al., 2003) comparing the soils that had been under conventional tillage or zero tillage for 21 years showed that SOC concentration was greater in zero till in the 0–5- and 5–10-cm layers. Small accumulation of SOC occurs, decreasing the movement of C from soil to the atmosphere. There is indication that this effect may be greater in tropical environments (Boddey et al., 2009).

Conservation Agriculture can mitigate effects of climate change through carbon sequestration in the soil, though this benefit may not be as large on a global level as has been hoped (Richards et al., 2014). Conservation agriculture practices together with best management practices in the rice- and wheat-based cropping systems of South Asia increased substantially whereas the global warming potential intensity decreased. As further noted in the south Asia system, (Ladha et al., 2016), positive economic returns were realized and less use of water, labour, nitrogen, and fossil fuel energy per unit food produced were also achieved. This in overall reduce GHG emissions. Through greater adoption of conservation agricultural systems, as explained by (FAO, 2008), there is enormous potential to sequester soil organic carbon, which would: (1) help mitigate greenhouse gas emissions contributing to global warming and (2) increase soil productivity and avoid further environmental damage from the unsustainable use of inversion tillage systems, which threaten water quality, reduce soil biodiversity, and erode soil around the world.

As options to increase carbon sequestration are sought, there is the need for international action to decrease current rates of land-use changes, especially deforestation and drainage of peaty wetland soils, which are leading to emissions of C from soils and vegetation, in other words, the opposite of C sequestration. In addition, as pointed by (Powlson et al., 2016), identify ways to decrease emissions of non-CO2 gases from agricultural practices, in view of the estimate by the IPCC (2007a) that 70% of the total GHG emissions from agriculture are associated with N fertilizer: a combination of CO2 and nitrous oxide (N2O) from its manufacture and N2O emissions, direct and indirect, from its use. This is because studies have projected that N2O and methane, have, respectively, 298 and 25 times the global warming potential of CO2 when considered on a 100-year time scale (IPCC, 2007).

2.9 Adoption of conservation agriculture

Conservation Agriculture is being increasingly promoted as constituting a set of principles and practices that can make a contribution to sustainable production intensification (FAO, 2008; Pretty, 2007) because it addresses missing components in the intensive tillage-based standardized seed-fertilizer-pesticide approach to agriculture intensification. According to a recent analysis of global spread of conservation agriculture (Kassam et al., 2019), Conservation Agriculture is practiced on nearly 181 million ha globally. This is as a result of gradual increase since 2008/09 (baseline) at a rate of 10 million ha per year. Africa has about 1.5 million hectares, an increase of some 650,000 ha since 2008/09. Conservation agriculture in recent years has become a fast-growing production system. While in 1973/74 the system was used only on 2.8 million ha worldwide, the area had grown to 6.2 million ha in 1983/84 and to 38 million ha in 1996/97 (Farooq & Siddique, 2015; Kassam et al., 2009). In 1999, worldwide adoption was 45 million ha (Derpsch et al., 2010), and by 2003 the area had grown to 72 million ha). In the last decade, conservation agriculture system has expanded at an average rate of more than 10 million ha per year to the current 181 million ha showing the increased interest of farmers in this technology as shown in Table 4 (Kassam et al., 2019). The growth of the area under conservation agriculture has been especially rapid in South America where the countries are using the system on about 70% of the total cultivated area (Derpsch & Friedrich, 2009).

Table 4: CA adoption in the world showing Cropland area under CA (M ha) by region in 2015/16; CA area as % of global total cropland, and CA area as % of cropland of each region

Region	**CA Cropland area**	**Per cent of global CA cropland area**	**Per cent of Cropland area in the region**
South America	69.90	38.7	63.2
North America	63.18	35.0	28.1
Australia & NZ	22.67	12.6	45.5
Asia	13.93	7.7	4.1
Russia & Ukraine	5.70	3.2	3.6
Europe	3.56	2.0	5.0
Africa	1.51	0.8	1.1
Global total	180.44	100	12.5

Source: (Kassam et al., 2019)

Globally, the total conservation agriculture area is still relatively small compared to the total arable areas using tillage. Yet this is changing, and the spread of conservation agriculture worldwide appears to have been expanding at the rate of 10.5 M ha per annum since 2008/09 (Kassam et al., 2019). The rate is however different in the different regions; in the North African region, much of the conservation agriculture work done in various countries has shown that yields and factor productivities can be improved with reduced tillage systems (Mkomwa et al., 2011). Extensive research and development work has been conducted in several countries since the early 1980s. Key lessons from international experiences about conservation agriculture and considerations for its implementation in the Mediterranean region have been summarized by (Lahmar, 2010) among other scientists. They all endorse the potential benefits that can be harnessed by farmers in the semi-arid areas.

Despite its promotion over the last fifteen years, adoption of conservation agriculture in Zambia is relatively limited. It was observed that 20% of conservation agriculture farmers in the 2002/3 season were spontaneous adopters, with the 80% majority practicing it as a condition for receiving subsidized input packages (Haggblade & Tembo, 2003). Conservational farming unit (CFU), a farmer support organisation, reports that around 170,000 farmers had adopted conservation agriculture on part or all of their land in 2011. Adoption tends to be incremental and partial in Zambia. In a different study (Umar, 2011) almost all farmers (out of 129 interviewed) practice both conventional and conservation farming on different plots. Research proved that 0.25 ha of carefully managed basin-planting conservation agriculture can provide a minimal food security safety net for a family of four (Haggblade & Tembo, 2003).

There are several underlying challenges that hinder rapid adoption of conservation agriculture. Traditional land tenure, uncontrolled or communal grazing and lack of sufficient soil cover, as well as socio-economic constraints are the major problems in the spreading of no-tillage in Africa (Chinseu et al., 2019). Research and development as well as diffusion strategies have to be directed towards solving these problems before no-tillage becomes an attractive alternative for farmers in Africa. On the other hand, labour constraints at the time of seeding in many regions of Africa may be an opportunity for this system to be adopted among farmers.

The adoption rates now in Africa (Kassam et al., 2014), are, South Africa has the highest area (368,000 ha), followed by Zimbabwe (332,000 ha), Zambia (200,000 ha), Mozambique (152,000 ha) and Malawi (65,000 ha) (Figure 3). Other notable countries include Kenya, Ghana, Tanzania, Tunisia, Madagascar, Morocco, Lesotho, Namibia, Sudan and Burkina Faso. Some large-scale farmers have been able to adopt profitable mechanized conservation agriculture in several countries such as South Africa, Zambia, Zimbabwe, Kenya, Tanzania, Morocco and Tunisia. However, in much of Africa, agriculture is dominated by smallholder farmers. They have different sets of drivers and challenges compared to large-scale farmers and they need support to adopt and practice conservation agriculture. Several participatory approaches to conservation agriculture adoption and scaling have been tested successfully. There are opportunities for Kenya and Tanzania to increase the land under conservation agriculture particularly in the semi-arid areas.

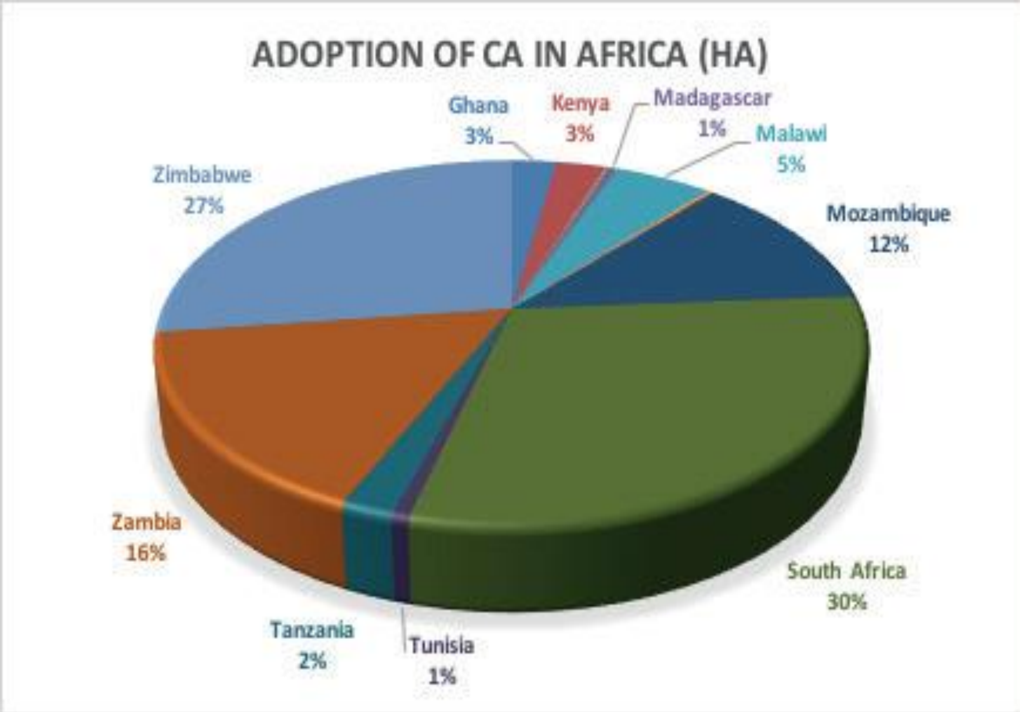

Figure 3: CA area in African countries as a percentage of the total land under CA in the region

Source: Kassam *et al.* (2014)

In Sub-Saharan Africa conservation agriculture is expected to increase food production while reducing negative effects on the environment and energy costs, and to result in the development of locally-adapted technologies consistent with conservation agriculture principles. (Friedrich et al., 2012). The challenges that limit its adoption in the region include; perception of limitations for conservation agriculture adoption; technical, biophysical, and economic constrains; legal and institutional framework; markets and communication constraints; socio economic constrains; credits, inputs, and equipment; and limited promotion and publicity (Kahimba et al., 2014).

Conservation agriculture or no-tillage systems will continue to grow worldwide as awareness increases of the fact that sustainability of agricultural production is a must if sustainable development at national and global level is to be achieved (Derpsch & Friedrich, 2009). However, for sustained growth to take place the main barriers to no-till adoption must be overcome. These include mindset (tradition, prejudice), knowledge on how to do it (know how), availability of adequate machines, availability of adequate herbicides and adequate policies to promote adoption (Johansen et al., 2012). To overcome these barriers, varied stakeholders must be involved including politicians, public administrators, farmers, researchers, extension agents and researchers. With adequate policies to promote Conservation Agriculture, it is possible to obtain what is called the triple bottom line, economic, social and environmental sustainability, while at the same time improving soil health and increasing production (Garnett et al., 2013). The wide recognition as a truly sustainable farming system should ensure the growth of this technology to areas where adoption is still small as soon as the barriers for its adoption have been overcome. The widespread adoption also shows that conservation agriculture cannot any more be considered a temporary fashion, instead the system has established itself as a technology that can no longer be ignored by politicians, scientists, researchers, extension workers, farmers as well as machine manufacturers and other agriculture related industries (Kassam et al., 2019).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The data for this study was collected in three different sites, the field experiment site, and the two social survey sites. To evaluate ecosystem services that conservation agriculture enhances, a field experiment was set up at the Department of Engineering farm in Sokoine University of Agriculture, Morogoro, Tanzania. The area is situated 6° S and 37 ° E and it is about 3km south of Morogoro Town. The university lies on the foot of the slopes of Uluguru Mountains at an elevation of about 500-550m above sea level.

The zone is dominated by sandy loam soil classified as Oxisol with pH of 5.16 and has a bimodal rainfall pattern where short rains occur from October to December and long rains start from March and ends in May (Mnyasa *et al*., 2003). The annual rainfall in this area ranges from 750 mm to 1050 mm with an average of 900 mm per annum. The temperatures of the area vary depending on the season, ranging between 30 °C – 35 °C during the hottest months (October to January) and 20 °C - 27 °C in the coolest months (April to August), (TMA, 2012).

The trial plots location lies between S 06 ° 50′12.9 ″ - S 06 ° 50′ 18.6″ and E 037° 38′ 37.9 ″ – E 037 ° 38′ 36.3″. The map of Tanzania in Figure 4 shows the location of the field experiment site.

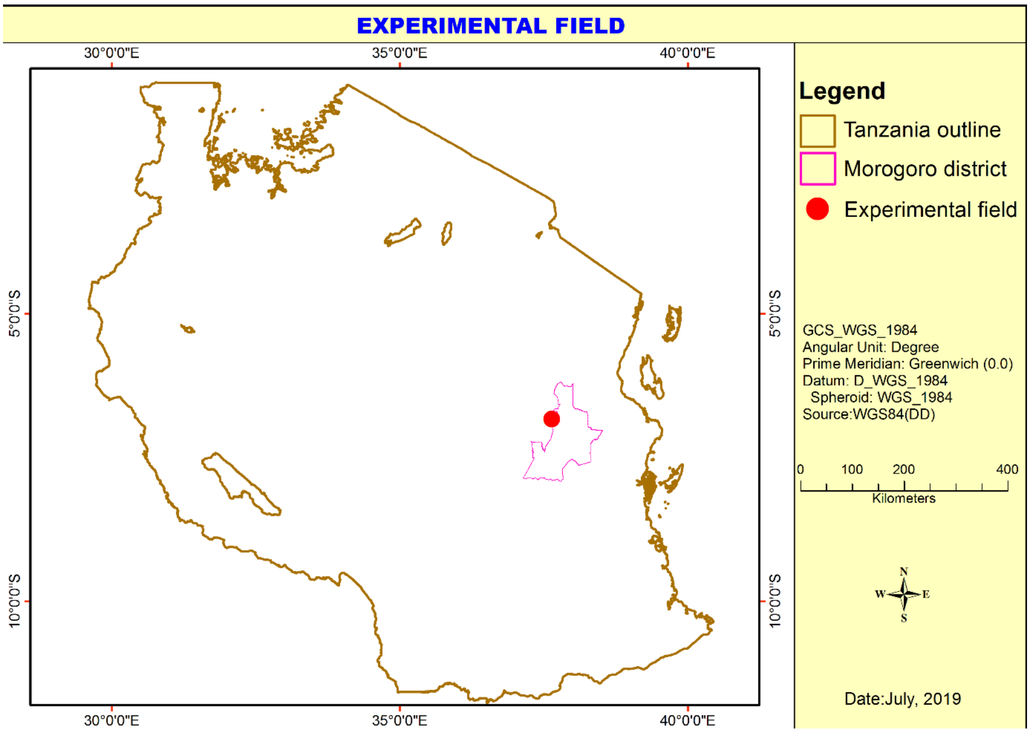

Figure 4: Map of Tanzania showing the experimental field location

To assess factors that affect the adoption of conservation agriculture, farmers were interviewed from Morogoro rural district, Tanzania and Bungoma county in Kenya (Figure 5).

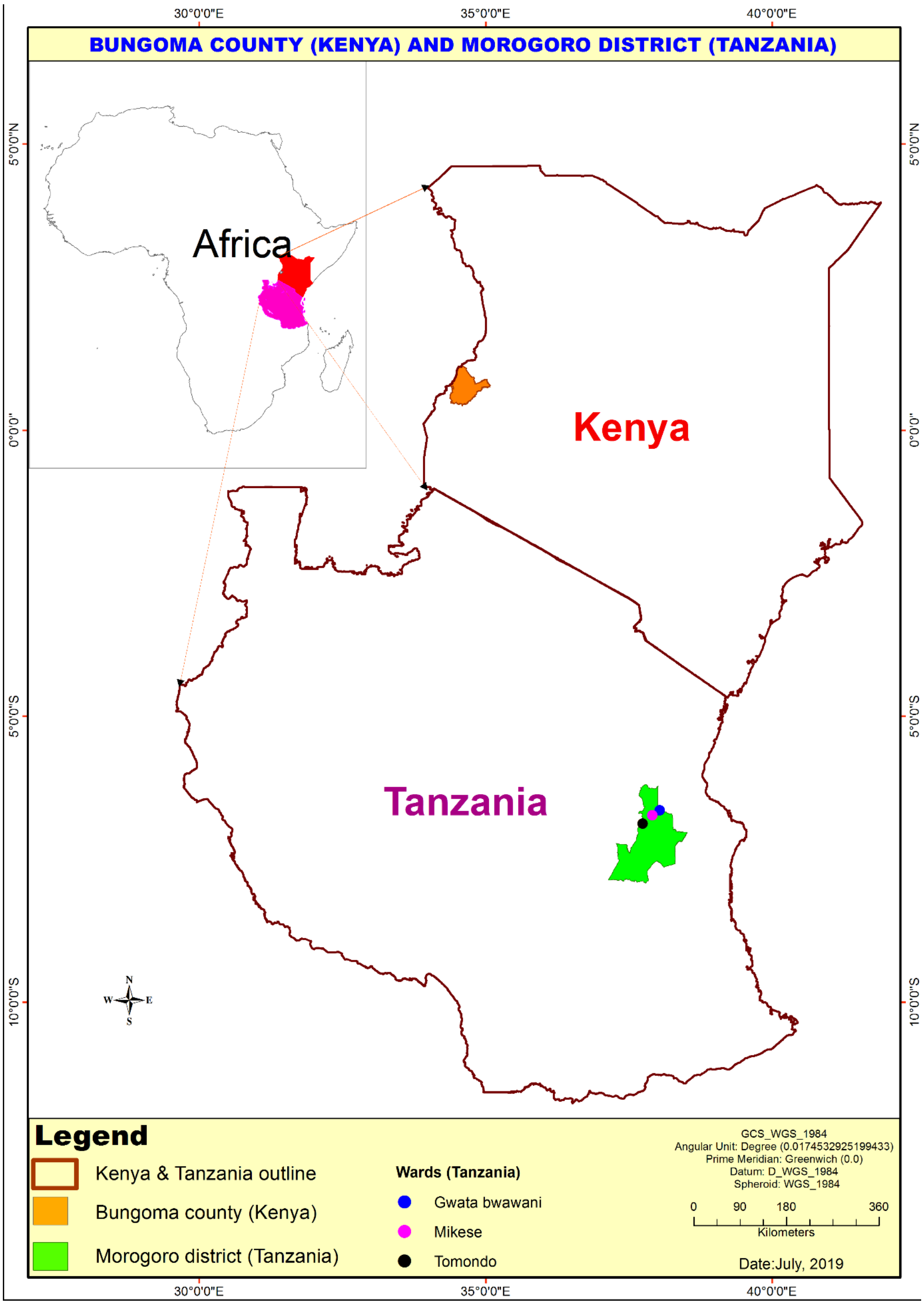

Figure 5: Map Showing the locations where the social survey was taken

3.2 Experimental design

A factorial arrangement of treatments in a randomized complete block design (RCBD) for split plot with three replications was laid out (Figure 6). The land under the experiment was 115 meters by 95 meters making a total area of 10925 meters square.

The experiment comprised two treatment factors; tillage and soil cover. Tillage was the main plot treatment and had six levels from both conventional and conservation tillage methods. The conservation agriculture tillage treatments were: Animal Ripping (AR), Tractor Ripping (TR), and Hand hoe Basin (HB); while the conventional agriculture tillage treatments were: Hand hoe Ridges (HR), Animal Ploughing (AP), and Tractor Ploughing (TP). The second factor, soil cover which was the sub-plot treatment, had three levels; 5 cm rice husks mulch (RH), 5 cm grass mulch (G), and Control with no soil cover (C). Figure 6 shows the arrangement of all the treatments in the experimental field.

Each tillage (main) plot measured 30 meters by 10 meters, replicated thrice (in three blocks) making a total of 18 main plots. Each of the main plots was then subdivided into three sub plots of 9 meters by 10 meters and treated with the second factor of soil cover (Figure 6). Therefore, making a total of 54 sub-plots or study units. An early maturing maize variety C.P. 201, was planted. Each plot was treated with Yara Mila cereal and Murate of Potash (MoP) fertilizer at planting. This was prepared by mixing 50 kg of Yara Mila cereal with 4kg of MOP to make a full dose per acre. Yara Mila cereal contains 23% N, 10% P, 5% K, 2% MgO, 3% S, 0.3% Zn while MoP contains Potassium and Chloride as basal fertilizer. Urea fertilizer was used for top dressing or booster fertilizer to supplement plant nutrients in the soil for all plots at the rate of 222 gm per plot. This was applied five weeks after planting. Three cropping seasons were planted. Season 1 ran from March to August 2018, season 2 from September 2018 to January 2019 and season three from February 2019 to July 2019.

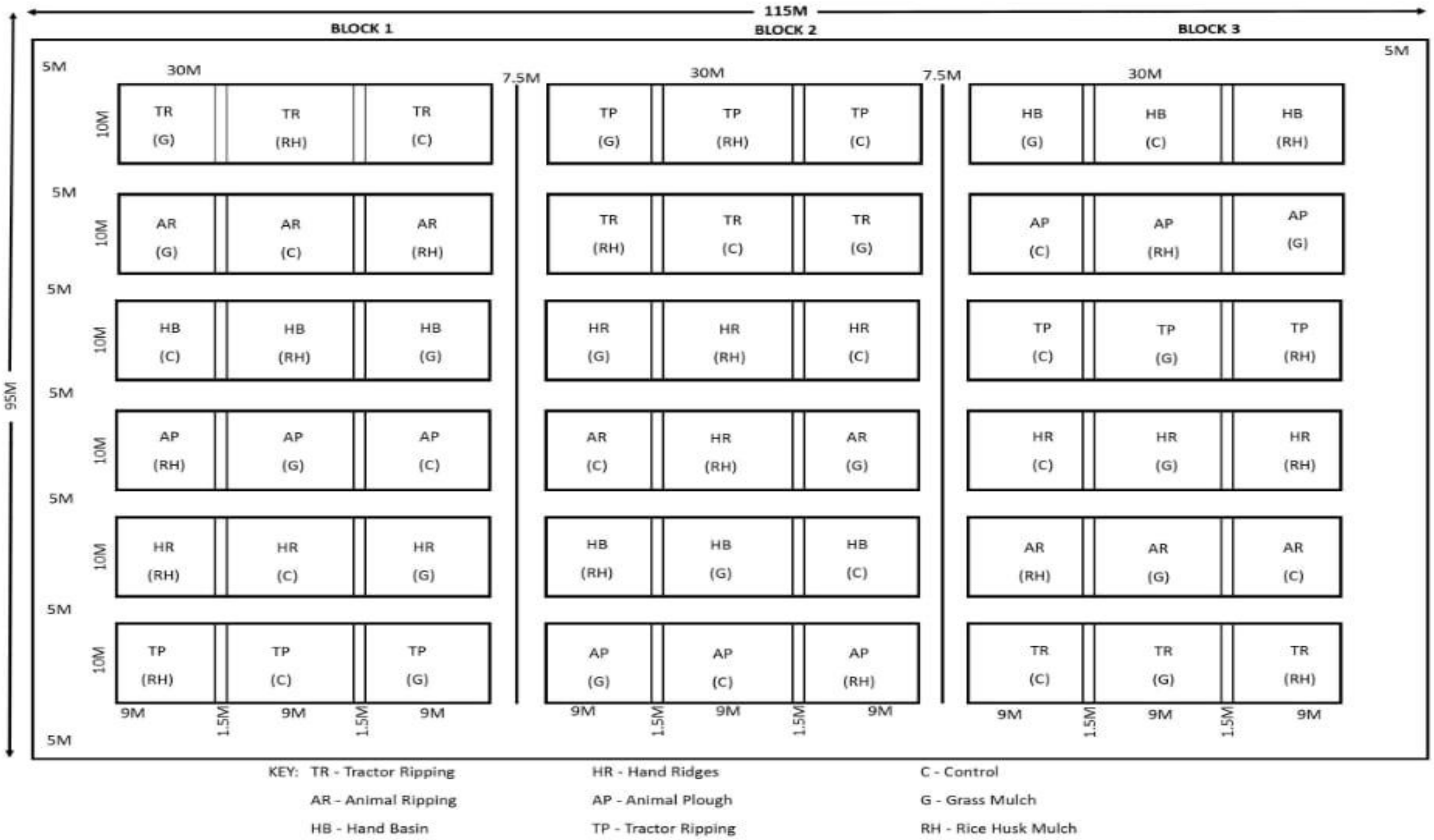

Figure 6: Experimental layout

3.2.1 Randomization procedure

Tillage treatments were randomized separately for each block/replicate. Each treatment had the same probability of being assigned to a given a plot within a block/replicate. Each treatment could only appear once per block/replicate. The variation between the tillage plots and blocks was minimized since they were all in the same elevation level. Figure 6 shows the random distribution of the treatments in the main plots and in the sub-plots.

Each main plot was divided into three sub plots of 9 meters by 10 meters, separated by 1.5-meter strips (Figure 6). Simple random procedure was used to allocate soil cover treatments of GRASS, RICE HUSKS and CONTROL, in the subplots for all tillage treatments in each block/replicate. The resulting lay out was maintained through the entire study.

3.2.2 Treatment descriptions

Tillage treatments:

(i) Conservation Agriculture Treatments

Animal ripping - Rip-lines were created at 10 cm depth and 10 cm width using an animal drawn ripper (Plate 1) which is smaller than the tractor drawn ripper. Seeds were then planted in the rip lines at an interval of 25 cm between seeds. The spacing between rip-lines was 75cm. Weeds were controlled using herbicides.

Plate 1: Land preparation in the animal ripping plot

Source: Author

Hand hoe basins – basins were dug with a hand hoe at 30 cm by 30 cm with 60 cm between rows. Two seeds were planted diagonally in the basin to reduce nutrient competition in the middle of the basin. Weeds were controlled using herbicides.

Tractor ripping - Rip-lines were created with a ripper drawn by a tractor (**Error! Reference source not found.**). It is bigger and makes deeper and wider rip lines in comparison to the animal ripper. A little soil was drawn back to reduce the depth of the rip line to 15 cm where the seeds were placed at an interval of 25 cm along the rip line. The spacing between rip-lines was 75cm. Weeds were controlled using herbicides.

Plate 2: Land preparation in the tractor ripping tillage plot
(Source: Author)

(ii) Conventional Tillage Treatments

Animal plough – seedbed was prepared using animal drawn mouldboard which is small than tractor drawn mould board. Planting holes were then made using a hand hoe at interrow spacing of 75 cm and 25 cm intra row spacing. Weeds were controlled by removal using a hand hoe.

Tractor plough – seed bed was prepared by mouldboard ploughing drawn by a tractor (Plate 3), planting holes were dug at inter-row spacing of 75 cm and intra row spacing of 25 cm. Weeds were controlled by removal using hand hoe.

Plate 3: Land preparation in the tractor plough tillage plot

(Source: Author)

Hand hoe ridges – narrow raised strips were made by scalping using a hand hoe (Plate 4). Seeds were planted on the ridge at an interval of 25 cm. Weeds were controlled through removal by shallow weeding using hand hoes.

Plate 4: Land preparation in the hand ridges plot using a hand hoe
(Source: Author)

Soil cover treatments:

Grass mulch – dry grasses cut within the experimental field along the paths and around the perimeter of the experimental land were placed on the relevant subplots at a depth of 5 cm

Rice husks – dry rice husks from rice farmers were imported to the experimental site and placed on the relevant sub plots at 5 cm depth (Plate 5). They were waste material from rice farmers and were readily available.

Control – no biomass material was applied to cover the soil in the sub plots that served as control for soil cover treatment.

Plate 5: Maize crop under rice husks mulch soil cover
(Source: Author)

3.3 Determination of maize production

At maturity of the maize crop, harvesting protocol followed CIMMYT recommended method where for every subplot, maize was harvested leaving out two guard/boarder rows around the plot. The harvested area is calculated and extrapolate to hectare (ha^-). Above ground biomass was weighed at harvesting. The maize was then dried to an acceptable moisture level of between 13% and 10% to avoid damage at shelling and for storage purposes. The moisture content must be less than 14% (Lewis et al., 2005) by grain moisture tester. The weight of the dried maize grains was taken for every subplot using a weighing scale. The 100-grain weight was measured for a sample of 100 grains randomly picked from the yield using the quartering method. The weighing was done in the laboratory using a microgram weighing scale.

3.4 Assessment of diversity and abundance of soil macro and microorganisms

Soil macro-organisms data was collected in the field experiment described in section 3.2. above, during the cropping seasons. The quadrat method was used to sample surface soil macro-organisms. Three random quadrats of 1 m^2 were diagonally placed in each sub-plot and sampled for macro-organisms. All present macro-organisms, in the quadrat, were identified and counted in the field. Sampling was carried out three times while the field experiment was running.

Diversity and abundance of soil macro-organisms were described and compared using Simpson's diversity index for the various tillage and soil cover systems. Macro-organisms' diversity for each tillage and soil cover system were converted to Simpsons Diversity Index (*D*). This is because true diversity cannot be described by numbers of individuals or species but rather an index of comparison. The index takes into account the richness and evenness of the samples, that is, the number of species present and the abundance of each species. To measure soil microorganism diversity and abundance, during the cropping season, soil samples were collected in all subplots in the field, in a zigzag pattern using a hand driven auger. A composite sample was obtained using the quartering and discarding method described by the Landon's soil sampling manual (Landon, 2014), to obtain 0.25 kg sample. It was then packed in a labelled zip lock airtight bag to ensure there was no contamination from non-sample microbes. The soil sample was refrigerated at 4^{o} C then passed through a sieve (1.7 mm mesh) to remove vegetation. An extract was prepared by sterile dilution using distilled water, and isolated using serial dilution up to 10^{-6} blank dilution as demonstrated in Figure 7. Using a sterile wire loop, the isolated sample was inoculated in a prepared media in saline solution (0.9% NaCl) on nutrient agar containing glucose, 10 g/L, NaCl, 1 g/L, peptone, 5 g/L, yeast extract, 3 g/L and agar 20 g/L. Sabouraud dextrose agar was used for cultivating fungi. The samples were incubated at 37ºC for seven days. The developed colonies were counted. The number of total bacteria, colony forming units (CFU) per gram dry weight of soil was determined.

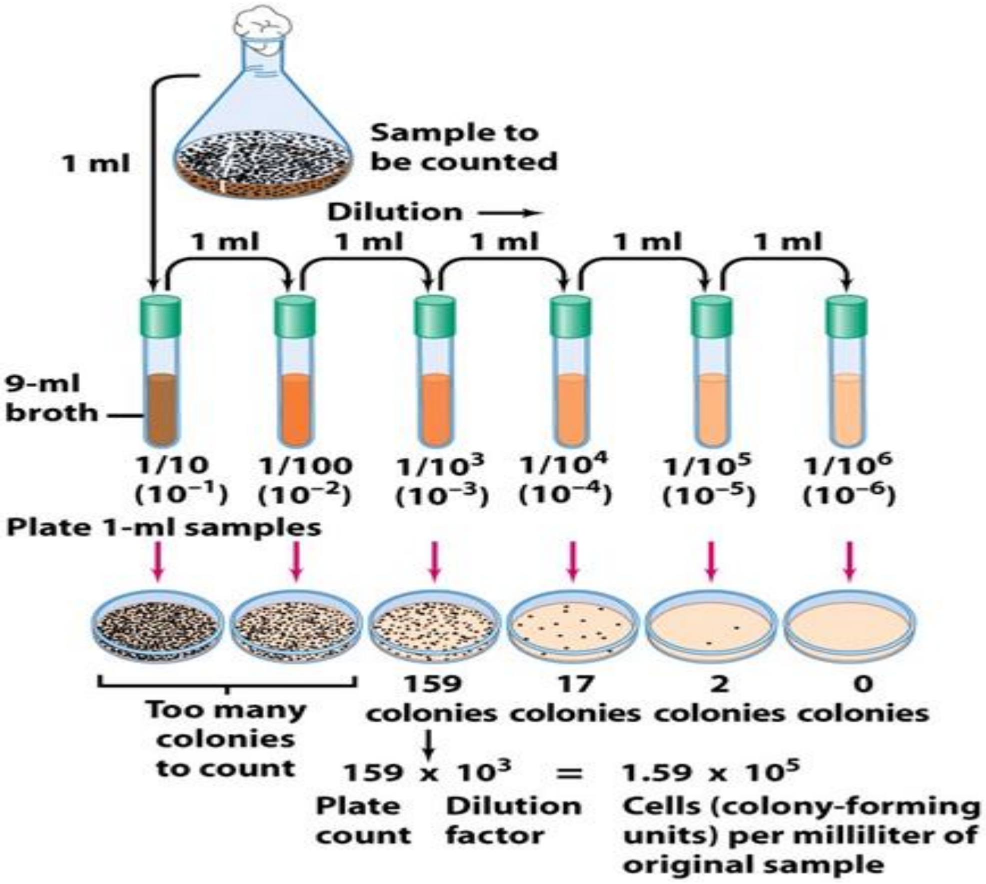

Figure 7: Serial dilution and plating procedure

(*Source: Al-Dhabaan & Bakhali, 2017*)

3.5 Evaluation of soil health

Soil health data was collected in the field experiment described in sections 3.2 above. Soil samples were collected for laboratory analysis of chemical properties. A sample was taken at the beginning of the experiment, and at the harvesting time of every cropping season. Soil samples were collected at two depths, 0 -15 cm (topsoil) and 15 - 30 cm (subsoil). The samples were randomly collected at three points (following a diagonal -lower, middle and upper- pattern) in each subplot. To obtain a composite sample, the three random samples were thoroughly mixed while spread on a PVC sheet and split into quarters by quartering and discarding method to obtain 0.25 kg sample (Landon, 2014). The samples were air dried at room temperature, ground to even size, then sieved through a 2 mm mesh sieve as per the procedures of laid out in the Methods of soil, plants and water analysis manual (Estefan et al., 2013), before determining its chemical properties.

Soil potential Hydrogen (pH) was measured using a pH meter to see how acidic or alkaline soils in each subplot were. It was measured in suspension with a deionized water ratio of 1:2.5 (Okalebo et al., 2002). Organic Carbon was determined using the modified Walkley-Black method. Total Nitrogen was measured using the modified Kjeldahl digestion-distillation-titration method. Extractable phosphorous was extracted using Bray I method because the pH for all the samples was less than 7. Potassium exchangeable bases were extracted with 1 N ammonium acetate solution at pH 7 (Landon, 2014; Okalebo et al., 2002).

3.6 Identification of factors affecting the adoption of Conservation Agriculture

To assess factors that affect the adoption of conservation agriculture, interviews were targeted to farmers that had been exposed to the knowledge of conservation agriculture through Sustainable Intensification of Maize-Legume Systems for Food Security in Eastern and Southern Africa (SIMLESA) project.

3.6.1 The SIMLESA project

The Sustainable Intensification of Maize-Legume Systems for Food Security in Eastern and Southern Africa (SIMLESA) project was funded through International Maize and Wheat Improvement Centre (CIMMYT) and implemented with the support of various local partners in the different countries where the project was implemented namely Ethiopia, Kenya, Malawi, Mozambique and Tanzania. The project worked with farmer groups with the following five objectives; (i) to support the development of local and regional agricultural innovation systems and scaling-out platforms, (ii) to enhance the understanding of conservation agriculture-based sustainable intensification for maize-legumes production systems, value chains and impact pathways, (iii) to increase the range of maize, legume and fodder/forage varieties available to smallholder farmers, (iv) To test and adapt productive, resilient and scalable conservation agriculture-based intensification options for sustainable smallholder maize-legumes production systems, (v) capacity building to increase the efficiency of agricultural research today and in the future (Siamachira & Mashango, 2015).

The farmers were exposed to different conservation agriculture practices including minimizing tillage, appropriate use of herbicides, improved seeds, mulching, crop residue retention and crop diversification. The small-scale farmers achieved different levels of conservation agriculture adoption, following the training on conservation agriculture.

3.6.2 The social survey

A quantitative and qualitative study with secondary research and interviews with farmers was carried in Morogoro Rural District, Tanzania and Bungoma county, Kenya. The target population in this study was farmers that had participated in conservation agriculture project, SIMLESA. A sample of 94 farmers was taken from three wards (Mikese, Gwata Bwawani, and Tomondo) in Morogoro Rural District, Tanzania; and 124 farmers from two sub counties (Kanduyi and Bumula) in Bungoma County, Kenya. The respondents were all taken from the localities where SIMLESA project was implemented. A questionnaire was developed by the researcher with both closed and open-ended questions focusing on farmers demographic information, agriculture and land experience, exposure to conservation agriculture, attitudes towards conservation agriculture and factors that influence adoption of conservation agriculture. (APPENDIX 1). It was pretested, adjusted, adopted and administered by the researcher. The respondent's responses were recorded.

3.7 Data analysis

Estimation and testing of the main effects of each factor (tillage and soil cover treatments) and the interaction among the factors on yield and soil health was carried out using GENSTAT software 14th Edition. The analysis of variance followed the linear model equation (i).

$Y_{ijk} = \mu + \alpha_i + \lambda_j + \varepsilon_{ij}^{w} + \beta_k + (\lambda\beta)_{jk} + \varepsilon_{ijk}^{s}$……………………………….(i)

$where;$

$\alpha_i, i = 1,2,3 \; is \; the \; block \; effect$

$\lambda_j, j = 1,2, \ldots,6 \; is \; the \; tillage \; effect \; (Whole \; plot \; factor)$

$\beta_k, k = 1,2,3 \; is \; the \; soil \; cov \; e \; r \; effect \; (Sub \; plot \; factor)$

$\varepsilon_{ij}^{w} \; = the \; whole \; plot \; random \; error \; term$

$\varepsilon_{ijk}^{s} = the \; sub \; plot \; random \; error \; term$

Statistical analysis software GENSTAT 14th edition was used for analysis and the hypotheses tested were as stated;

Hypothesis 1: H$_0$: The mean effect of the various tillage treatments is the same

Also stated as H$_0$: $\mu TR = \mu TP = \mu AP = \mu AR = \mu HB = \mu HR$

Where:

μTR= Mean of Tractor Ripping

μTP= Mean of Tractor Plough

μAP= Mean of Animal Plough

μAR=Mean of Animal Ripping

μHR= Mean of Hand Basin

μHR = Mean of Hand Ridges

Hypothesis 2: H_0: The mean effect of grass mulch, rice husks mulch and control (or no mulch) is the same

Also stated as H_0: $\mu G = \mu RH = \mu C$

Where:

μG = Mean of Grass mulch treatment,

μRH = Mean of Rice Husks treatment,

μC = Mean of Control/no mulch treatment.

The formula in equation (ii) was used to calculate the soil macro-organisms Simpson's diversity index of the sampled treatments.

$$D = \frac{\sum n(n-1)}{N(N-1)} \quad \text{(ii)}$$

Where;

n = the total number of individuals of a particular species of soil macro-organism

N = the total number of individuals of all species of soil macro-organisms

$0 \leq D \geq 1$

Infinite Diversity $\longleftrightarrow$ **No Diversity**

The value of *D* ranges between 0 and 1. This index is therefore interpreted as follows: 0 represents infinite diversity, and 1 represents no diversity. That is, the higher the value of *D*, the lower the diversity of the species. Non-parametric test for Diversity Indices from the different tillage systems and soil cover was carried out at 95% significance level, to establish any differences in the effects of tillage and soil cover on soil macro-organisms' diversity and abundance.

The abundance of soil microorganisms was presented in numbers of bacteria per sample which is based on each subplot. The exact numbers of bacteria colony units were large and make it manageable, they were converted to natural logs of the bacteria colonies count. They were then compared and ordered from the lowest to the greatest.

Testing of the effect of tillage and soil cover on soil health was carried out using repeated measure analysis of variance (ANOVA) for each parameter; Nitrogen, Phosphorous, Potassium, Organic Carbon and pH measured per plot for the three consecutive measurements taken at top and sub soil level. Significance test was performed at 95% confidence interval. The Linear model in equation (iii) was applied.

$$Y_{ijk} = \mu + \alpha_i + \lambda_j + \varepsilon_{ij}^{w} + \beta_k + (\lambda\beta)_{jk} + \varepsilon_{ijk}^{s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

$where;$

$\alpha_i, i = 1,2,3\ is\ the\ time\ effect$

$\lambda_j, j = 1,2, \ldots ,6\ is\ the\ tillage\ effect\ (Whole\ plot\ factor)$

$\beta_k, k = 1,2,3\ is\ the\ soil\ cov\ e\ r\ effect\ (Sub\ plot\ factor)$

$\varepsilon_{ij}^{w}\ = the\ whole\ plot\ random\ error\ term$

$\varepsilon_{ijk}^{s} = the\ sub\ plot\ random\ error\ term$

Statistical analysis software GENSTAT 14th edition was used for analysis and the hypotheses tested were as stated;

Potassium H_0: The level of K1=K2=K3

Phosphorous H_0: The level of P1=P2=P3

Nitrogen H_0: The level of %N1=%N2=%N3

Organic Carbon H_0: The level of OC1=OC2=OC3

pH H_0: The level of pH1=pH2=pH3

The measured values of soil health parameters were also compared with the recommended critical values using two-tailed one sample t-test since the critical value for maize production (Landon, 2014), is the known population mean. Testing whether the observed value is different from the expected value for a healthy soil using Alpha = 0.05, or confidence level of 95%. The hypothesis tested for each parameter is shown in Table 5.

Table 5: Hypotheses for the various soil parameters

Soil Parameter	Critical range	Test mean	Null Hypothesis	Alternate Hypothesis
Potassium ($CmolKg^{-1}$)	0.2-0.4	0.3	$\mu K = 0.3$	$\mu K \neq 0.3$
% Nitrogen	0.2-0.4	0.3	$\mu N = 0.3$	$\mu N \neq 0.3$
% Organic Carbon	4.0-10	7	$\mu OC = 7$	$\mu OC \neq 7$
Phosphorous ($mgkg^{-1}$)	10.0-15	12.50	$\mu P = 12.5$	$\mu P \neq 12.5$
pH	5.5-7.0	6.25	$\mu pH = 6.25$	$\mu pH \neq 6.25$

For factors affecting the adoption of conservation agriculture, the data collected through the questionnaire was organized in a spread sheet and analysed using SPSS. Descriptive statistics was used to describe the data, while inferential statistics including paired t-test, and chi square were used to establish statistical significance and correlations of the findings. The data was presented in graphs and tables.

CHAPTER FOUR

RESULTS

4.1 Determined maize production

These results are based on the objective that sought to determine the maize production in conservation and conventional tillage systems. It is presented in weight of above ground maize biomass and weight of maize grain that were harvested. It tested the hypothesis that the weight of the above ground biomass and maize grains in conservation and conventional tillage systems are the same. The weather data viz rainfall and temperature were also taken into account and is presented for comparison with the observed maize growth and yields.

4.1.1 Weather data

Weather data comprising maximum temperature, minimum temperature and rainfall were recorded during the field trial period from March 2018 to June 2019 (Figure 8). Season 1 ran between March and August 2018, season 2 between September 2018 and January 2019, while season three run between February and July 2019. Season one and three, the long rains seasons had rainfall of between 250 mm and 300 mm at planting and early growth. The rainfall reduced to 150 mm during tussling and grain filling and eventually to about 0 mm during harvesting. During the long rain seasons, the temperatures were also high with maximum temperature ranging from 27.1°C to 30.5°C while the minimum temperature ranged from 16.5°C to 21.2°C. In season two, the short rains season, the rainfall at planting and early development was only 4.8 mm and therefore watering the fields was inevitable. The rainfall increased gradually and at tussling and grain filling it raised up to 81.6 mm and later dropped during harvesting time. At this period, the temperatures were high with the maximum temperature ranging from 30.9ºC to 32.6ºC and the minimum temperature ranging from 17.1ºC to 22.7ºC.

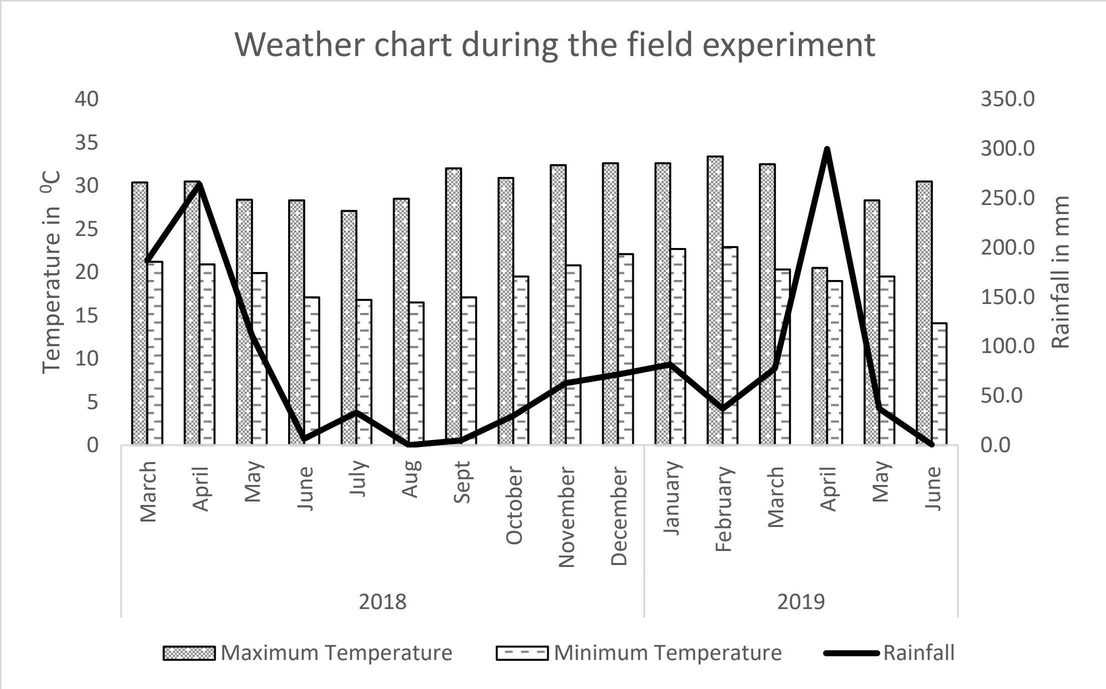

Figure 8: Weather Chart for Morogoro during the field experiment period

4.1.2 Effects of tillage and soil cover on above - ground maize (*Zea mays*) biomass

The mean effect of soil cover treatment (grass, rice husks and no mulch) on above-ground maize biomass in all seasons, was significantly different at 95% confidence level with a p-value of 0.006 and 0.002 for season one and two respectively and at P-value of 0.03 in season 3 (Table 6). However, tillage practices did not significantly affect above ground biomass yield and there was also no significant interaction between tillage practices and soil cover.

Table 6: ANOVA results of the effects of tillage and soil cover on above-ground biomass of maize

Source of variation	**P - values**		
	Season 1 (Long rain 2018)	**Season 2 (Short rain 2018)**	**Season 3 (Long rain 2019)**
Tillage treatment	0.834	0.061	0.440
Soil Cover treatment	0.006**	0.002**	0.030**
Interaction between Tillage and Soil Cover treatments	0.888	0.136	0.180

*Key: ** significant at 95% (p <0.05)*

Mulch significantly ($P < 0.05$) affected above ground maize biomass but the tillage practices did not. Rice husk mulch resulted in significantly ($p < 0.5$) higher yields than the control (no mulch) treatment in both seasons one and two, while grass mulch significantly increased biomass yield in seasons two and three (Table 6). There was no statistical difference on biomass yields between the grass mulch and the rice husk mulch in seasons one and two. However, in the long rain season (season three) grass mulch had significantly higher yield than the control and rice husk mulch treatments (Table 7).

Table 7: Effects of different soil cover treatments on above-ground maize biomass

Soil cover treatment	**Biomass yield in kg ha^{-1}**		
	Season 1 (Long rain 2018)	**Season 2 (Short rain 2018)**	**Season 3 (long rain 2019)**
Control/No Mulch	6,110.8a	10,686.2a	9,245a
Grass Mulch	6,716.8ab	11,830b	10,058b
Rice Husks Mulch	7,400.9b	12,022.3b	9,372a

Key: means followed by the same letter within a column are not significantly different

The effect of tillage treatments on biomass yields was not significant in the short rain season. During this season, Hand Basin, Animal Ripping, and Tractor Ripping significantly increased biomass yields when compared to Hand Ridges tillage (Figure 9). However, tractor plough and animal plough did not significantly affect biomass yield when compared to the control and other treatments.

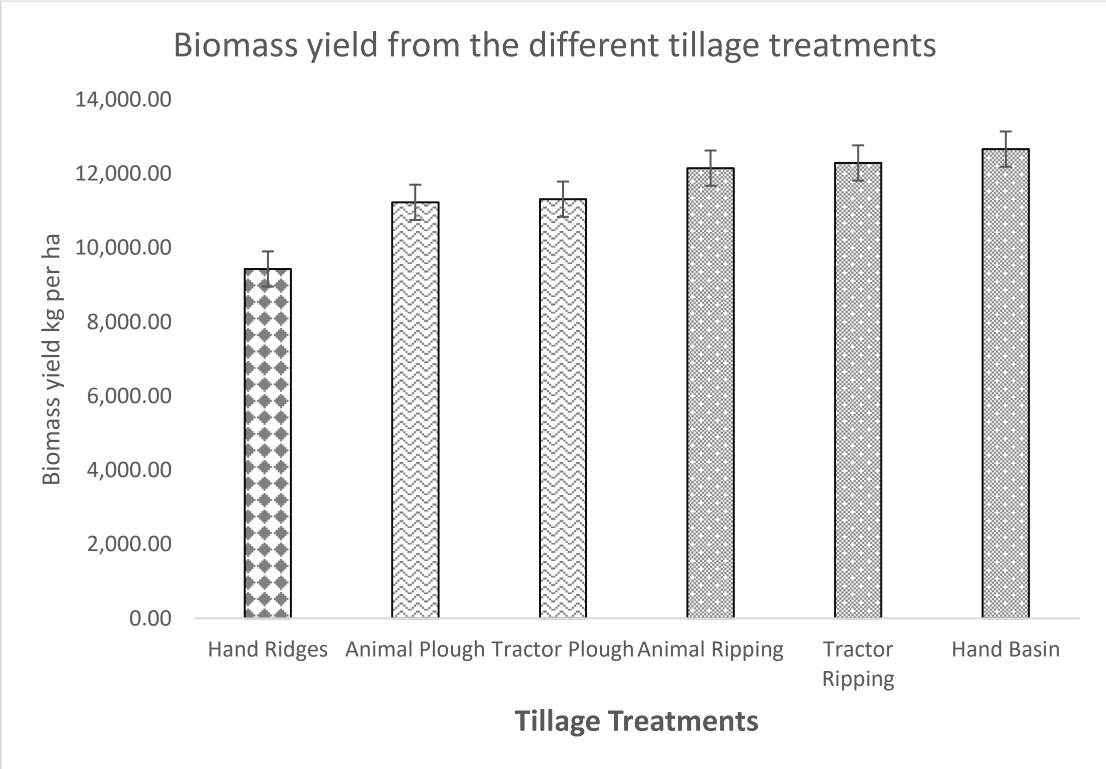

Figure 9: Effects of tillage treatment on above ground maize biomass in short rains season in 2018.

4.1.3 Effects of tillage and soil cover on maize grain weight

Mulching treatments generally increased maize grain weight but tillage practices did not significantly affect maize grain yield. The mean effect of the three soil cover treatments on maize grain yield were significant at $p = 0.048$ and 0.094 during the long rain seasons (seasons 1 and 2) and $p = 0.001$ during the short rain (Table 8) season. A post hoc test for the mean effects of the different soil cover treatments shows that in long rain season (seasons 1), control or no mulch cover treatment resulted in significantly lower grain weight than the Rice husks mulch, but grass mulch did not differ significantly from either control or Rice husks mulch (Table 9). However, in the long rain season (season 3) grass mulch significantly increased maize grain yield over the control.

Table 8: ANOVA results of the effects of tillage and soil cover on maize grain weight

Source of variation	**P - values**		
	Season 1 (Long rain 2018)	**Season 2 (Short rain 2018)**	**Season 3 (Long rain 2019)**
Tillage treatment	0.949	0.125	0.496
Soil Cover treatment	0.048**	<0.001**	0.094
Interaction between tillage and soil cover treatments	0.914	0.012**	0.232

*Key: ** significant at 95% (p <0.05)*

Table 9: Effects of soil cover treatments on maize grain weight in kg ha^{-1}

Soil cover treatment	**Maize grain weight in kg ha^{-1}**		
	Season 1 (Long rains 2018)	**Season 2 (Short rains 2018)**	**Season 3 (Long rains 2019)**
Control	2,368.5a	4,898.6a	5,376a
Grass Mulch	2,638.8ab	5,768.0b	5,724b
Rice husks mulch	2,771.2b	5,790.3b	5,480ab

Key: means in the same column followed by different letter are significantly different

On the other hand, the mean effect of the six tillage types on grain weight was not significantly different in both seasons but there was a significant (p = 0.012) interaction between tillage and soil cover during the short rain season (Table 8). A univariate analysis of variance and a post hoc test using multiple comparisons for the interactions separated the effects of interactions.

Hand basin (conservation tillage) with no mulch increased the weight of maize grains significantly while hand ridges with no mulch did not (Table 10). Animal and tractor ripping with grass mulch which are conservation agriculture also increased the yield.

Hand ridges (conventional tillage) with grass mulch did not increase maize yield. There did not seem to be a specific trend among the other interactions of tillage and soil mulch and how they affected maize yield.

Table 10: Effects of interactions between tillage and soil cover on maize yield.

Interactions between tillage and soil cover treatments	**Mean weight of maize yield (kgha^{-1})**
Hand Ridges (HR) Rice Husks Mulch	4021a
Hand Ridges (HR) Grass Mulch	4231ab
Tractor Ripping (TR) Rice Husks Mulch	4745abc
Animal Plough (AP) Rice Husks Mulch	4961abcd
Tractor Plough (TP) Rice Husks Mulch	5064abcde
Hand Basin (HB)Rice Husks Mulch	5177abcde
Animal Plough (AP) Control	5219abcdef
Tractor Plough (TP) Grass Mulch	5232abcdef
Tractor Plough (TP) Control	5370abcdef
Animal Ripping (AR) Rice Husks Mulch	5423abcdef
Hand Ridges (HR) Control	5511abcdef
Hand Basin (HB) Grass Mulch	5654bcdef
Animal Ripping (AR) Control	5757bcdef
Tractor Ripping (TR) Control	5958cdef
Animal Plough (AP) Grass Mulch	6405def
Animal Ripping (AR) Grass Mulch	6576ef
Tractor Ripping (TR) Grass Mulch	6639ef
Hand Basin (HB) Control	6792f

Key: means followed by the same letter are not significantly different

4.1.4 Effects of tillage and soil cover on 100 maize seeds weight

The mean effect of tillage on 100 seeds of harvested maize was significantly different in the long rain seasons $p < 0.001$ and $p = 0.026$ (Table 11). Similarly, the mean effect of soil cover treatments was significantly different in all the three seasons. In addition, there were significant interaction ($p < 0.001$) in the third season between tillage and soil for 100 seeds.

Table 11: ANOVA results for the effects of treatments on 100 maize seeds weight

Source of variation	P - values		
	Season 1 (Long rain 2018)	**Season 2 (Short rain 2018)**	**Season 3 (Long rain 2019)**
Tillage treatment	<0.001**	0.321	0.026**
Soil Cover treatment	0.066	<0.001**	<0.001**
Interaction between tillage and soil cover treatments	0.156	0.131	<0.001**

*Key: ** significant at 95% (p <0.05)*

Hand Basin tillage had the highest mean 100 seed weight of 30.23 grams in season 1 when compared to hand ridges but not with other tillage practices. In season, 3 Animal Ripping tillage had the highest mean of 32.62 grams when compared to tractor plough (Table 12) but was not statistically different from other tillage practices.

Table 12: The effects of tillage treatments on 100 seeds weight

Tillage treatment	100 seeds weight in grams	
	Season 1 (Long rains 2018)	**Season 3 (Long rains 2019)**
Tractor Plough	28.90bc	30.49a
Hand Basin	30.23c	31.24ab
Hand Ridges	25.23a	31.26ab
Animal Plough	27.82b	31.81bc
Tractor Ripping	28.98bc	31.86bc
Animal Ripping	28.38b	32.62c

Key: means in the same column followed by the same letter are not significantly different

In the seasons 2 and 3, the mean of 100 seeds weight in soil mulch treatments was significantly increased compared to the no mulch treatment (Table 13). However, in season one all mulch treatments increased 100 seed weight but the results were only significantly different when rice husks mulch is compared to no mulch.

Table 13: The effects of soil cover treatments on 100 seeds weight

Soil cover treatment	100 seeds weight in grams		
	Season 1 (Long rains 2018)	**Season 2 (Short rains 2018)**	**Season 3 (Long rains 2019)**
Control	27.59a	24.63a	30.01a
Grass Mulch	28.24ab	27.50b	32.15b
Rice Husks Mulch	28.94b	27.28b	32.47b

Key: means in the same column followed by the same letter are not significantly different

The interaction between tillage and soil cover was significant in season 3. Animal ripping with rice husks mulch increased the weight of 100 seeds compared to interactions of hand basin, tractor ripping, tractor plough, and hand ridges with no mulch which had low means (Table 14).

Table 14: Effects of interactions between tillage and soil cover on weight of 100seeds in season 3

Interactions between tillage and soil cover	**Weight of 100seeds (grams)**
Hand Basin (HB) Control	28.22a
Tractor Ripping (TR) Control	29.55ab
Tractor Plough (TP) Control	29.98ab
Hand Ridges (HR) Control	30.22abc
Tractor Plough (TP) Rice Husks Mulch	30.50bcd
Hand Ridges (HR) Rice Husks Mulch	30.75bcde
Animal Plough (AP) Control	30.95bcde
Tractor Plough (TP) Grass Mulch	30.99bcde
Animal Ripping (AR) Control	31.14bcde
Hand Basin (HB)Rice Husks Mulch	31.66bcdef
Animal Ripping (AR) Grass Mulch	31.70bcdef
Animal Plough (AP) Rice Husks Mulch	31.92bcdef
Animal Plough (AP) Grass Mulch	32.56cdef
Hand Ridges (HR) Grass Mulch	32.81defg
Tractor Ripping (TR) Grass Mulch	32.93efg
Tractor Ripping (TR) Rice Husks Mulch	33.09efg
Hand Basin (HB) Grass Mulch	33.84fg
Animal Ripping (AR) Rice Husks Mulch	35.01g

Key: means followed by the same letter are not significantly different

4.2 Diversity and abundance of soil biodiversity

These results are based on the objective that aimed at assessing the diversity and abundance of soil macro and microorganisms in both conservation and conventional tillage systems. It was based on the null hypothesis that there is no difference in the diversity and abundance of soil macro and microorganisms found in the different tillage and soil cover systems.

4.2.1 Diversity and abundance of soil macro-organisms

A total of 6513 individuals from 20 species and 19 Orders of macro fauna were encountered in the experimental field (Table 15). Ants were the most dominant fauna with 4676 individuals making about 72% of all the macro-organisms counted. This was followed by the cockroaches (518 individuals), millipede (316 individuals), crickets (245 individuals) and termites (226 individuals). The abundance of macro-organisms was higher during the first season compared to season 3 (Table 15). Conservation Tillage with grass mulch had the greatest number of species encountered across the seasons followed by conventional tillage with grass mulch. Across the entire study, ants were the most abundant species constituting 72% of all the individuals encountered. Frog, lizard, mantid and mosquito were the least dominant species encountered with only one individual in a quadrat. The lizard and frog were also encountered hiding in litter, although this was rare, it is significant since they form part of the food web.

Table 15: Summary of Soil Macrofauna species and numbers found in the experimental plots

Species	Order	Season 1 – Long rain 2018						Season 2 – Short rain 2018						Season 3 – Long rain 2019						
		A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	Total
Ant	Hymenoptera	588	608	535	640	592	742	39	109	38	43	69	30	85	128	82	84	151	113	4676
Beetle	Coleoptera	2	9	3	2	10	5	0	3	1	2	10	0	1	2	3	1	9	0	63
Stink bug	Hemiptera	0	0	0	3	2	1	0	0	0	0	0	0	2	2	1	0	1	3	15
Butterfly	Lepidoptera	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	12	1	17
Centipede	Chilopoda	2	52	10	12	51	3	0	9	0	0	1	1	1	10	2	1	0	11	166
Cockroach	Blattodea	4	94	2	3	136	6	19	71	7	21	71	7	14	41	21	15	33	16	581
Cricket	Orthoptera	0	20	2	2	27	4	15	12	5	2	21	5	17	22	23	14	36	18	245
Dragonfly	Odonata	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	7
Earthworm	Haplotaxida	2	0	4	8	10	4	2	5	5	6	5	0	0	1	0	0	0	0	52
Fall Army Worm	Lepidoptera	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	4
Frog	Anura	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Grasshopper	Orthoptera	0	1	1	0	1	0	1	0	0	0	0	0	4	0	2	0	3	1	14
Lizard	Squamata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Mantid	Mantodea	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Millipede	Diplopoda	1	8	5	7	13	3	25	46	28	23	66	23	8	15	14	5	12	14	316
Mosquito	Diptera	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Slug	Onchidiacea	0	0	0	0	0	0	1	6	2	5	1	2	0	0	0	0	0	0	17
Snail	Achatinoidea	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Spider	Araneae	3	31	4	5	46	5	1	0	0	0	1	0	0	0	3	0	0	6	105
Termites	Blattodea-Isoptera	1	3	1	1	1	0	2	9	2	5	10	0	21	46	29	21	39	35	226
Total Individuals		604	828	568	685	893	774	105	270	88	109	255	68	160	271	180	141	296	218	6513
Species		9	10	11	12	14	10	9	9	8	10	10	6	11	11	10	7	9	10	20
Diversity Index D		0.96	0.56	0.90	0.89	0.48	0.93	0.26	0.27	0.32	0.26	0.23	0.34	0.33	0.42	0.32	0.29	0.28	0.35	

Key for Table 15: Summary of Soil Macrofauna species and numbers found in the experimental plots; Letters A – F represent Tillage and Mulch treatments as;

A = Conventional Tillage & No Mulch, B = Conventional Tillage & Grass Mulch

C = Conventional Tillage & Rice husks Mulch, D = Conservation Tillage & No Mulch

E = Conservation Tillage & Grass Mulch F = Conservation Tillage & Rice husks Mulch

Some of the macro-organisms sampled are pests for example, Fall Army Worm, *Spodoptera frujiperda* that was recently discovered in Africa. The numbers counted were few since the moth is mostly found inside maize crop and not on the soil surface. There were few earthworms encountered and this could be attributed to the fact that they burrow, yet the study focussed on the soil surface. Therefore, the numbers observed do not include any organisms below the soil surface level. Out of the total number of 20 species encountered, conservation tillage with grass mulch had the highest representation of 14 species and 893 individuals making 13.7 percent of the total number of individuals encountered in the 18 different units.

The average diversity in the study area D = 0.47 (Table 16), since it is less than 0.5, the median of the 0 - 1 range is considered relatively high (the closer Diversity Index D is to 0 the more the diversity, the closer it is to 1, the less the diversity). Conservation tillage with grass mulch treatment was the most diverse in all the three seasons of macro-organisms sampling. Although the exact diversity index varied between the seasons; D = 0.47; 0.23; 0.28 for seasons 1, 2 and 3 respectively, (Table 16) the trend remained similar in all seasons. The most diverse tillage system was conservation tillage in season two D = 0.28. The most diverse soil cover treatment was grass mulch D = 0.37. In the control soil cover with no mulch, the most diverse was the treatment with conservation tillage in season two, D = 0.26. In an overview of the soil cover treatments, rice husks mulch was the least diverse, with an average diversity D = 0.53. Peculiarly, the highest diversity among the rice husks treatment was the conventional tillage in season three D = 0.32 (Table 16).

Table 16: Diversity Indices (D) for soil macro-organisms

Season	**Tillage**	**Soil Cover**			**Average**
		No Mulch	Grass Mulch	Rice husks Mulch	
1	Conservation	0.89	0.47*	0.93	**0.77**
	Conventional	0.96	0.56	0.90	**0.81**
2	Conservation	0.26*	0.23*	0.34	**0.28***
	Conventional	0.26	0.27	0.32	**0.28**
3	Conservation	0.29	0.28*	0.36	**0.31**
	Conventional	0.33	0.41	0.32*	**0.35**
	Average	**0.50**	**0.37***	**0.52**	**0.47**

*Key: * the highest diversity in its category (Tillage and soil cover)*

Independent sample Kruskal Wallis non-parametric test on diversity indices for the three seasons showed significant differences (p = 0.002). A pairwise comparison between the diversity indices showed that the diversity of macro-organisms increased significantly in season 2 compared to season 1 but not with season 3 (Table 17).

Table 17: Separation of diversity indices

Group	**Kruskal Wallis rank**
Season 1 (Long rains 2018)	15.50a
Season 2 (Short rains 2018)	4.67b
Season 3 (Long rains 2019)	8.33ab

Key: the ranks followed by the same letter are not significantly different

An average of the diversity indices for each season was matched with the rainfall and temperature data (Table 18). Season 2 with the highest diversity of macro-organisms had the highest rainfall and lowest temperature range. This confirms the results of the non-parametric test that the highest diversity was in season two, due to favourable weather conditions.

Table 18: Average season Diversity Index compared to weather parameters

Season	Diversity Index (D) (Average)	Temperature (ºC) (Min-Max)	Rainfall (mm)
1	0.786	19.5 – 30.9	29.6
2	0.281	19.0 – 20.5	299.8
3	0.331	14.1 – 30.5	0.6

4.2.2 Diversity and abundance of soil microorganisms

Following extraction, isolation, inoculation and incubation, all the tillage and soil cover treatment plots had whitish-black cottonlike colonies of fungi (Plate 6). Although it was not possible to count the cotton like fungi, the study confirmed that every tillage and soil cover treatment had presence of the fungi.

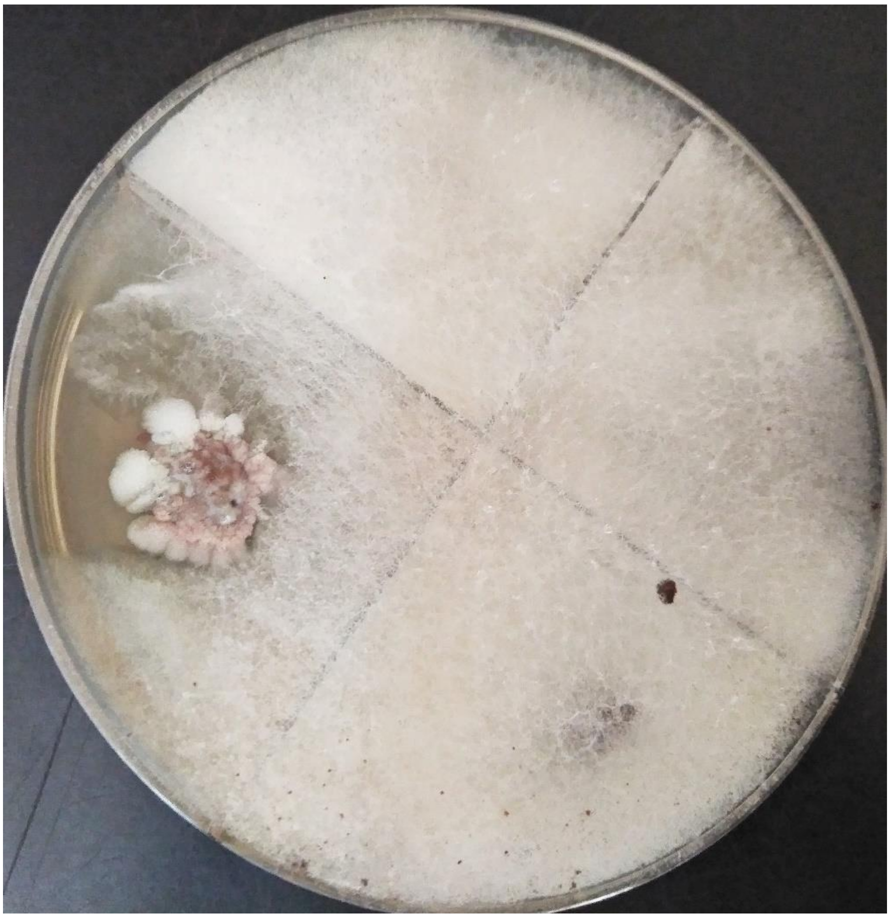

Plate 6: Cottonlike colonies of fungi

(Source: Author)

Bacteria in all tillage and soil cover plots registered 100% growth, were white in colour, and the colonies were rough in shape and came in medium and large sizes (Plate 7). In 8 out of 18 treatments, (Animal Plough Control, Animal Plough Grass, Animal Plough Rice husks, Animal Ripping Rice husks, Hand Basin Rice husks, Hand Ridges Control, Tractor Plough Rice husks, Tractor ripping grass) the bacteria colonies were too many for direct count (Plate 7). Therefore, this study modified concepts to a model for estimating the numbers using the diameter of the Petri dish and a count for a small area of 1 cm^2 then extrapolate for the entire area of the Petri dish (Bunge, 2009; Bunge et al., 2014; Jeon et al., 2006) . The counted bacteria colonies numbers are presented in (Table 19).

Analysis of various for natural logarithms of bacteria numbers (Table 19) showed that tillage treatments with or without mulch did not significantly affect the numbers of bacteria colonies. The microorganisms were high in all the treatments.

Table 19: Number of Bacteria Colonies counted

Tillage	Soil Cover	Total Bacterial colonies count	Natural Logs of Bacteria colonies count
Animal plough	Control	1×10^{100}	25.33
Animal plough	Grass	1×10^{100}	13.59
Animal plough	Rice husks	1×10^{100}	22.29
Animal ripping	Control	8.0×10^{5}	25.33
Animal ripping	Grass	8.0×10^{8}	9.49
Animal ripping	Rice husks	1×10^{100}	8.63
Hand basin	Control	4.8×10^{9}	25.33
Hand basin	Grass	4.0×10^{6}	20.50
Hand basin	Rice husks	1×10^{100}	15.20
Hand ridges	Control	1×10^{100}	16.17
Hand ridges	Grass	1.05×10^{7}	22.52
Hand ridges	Rice husks	1.88×10^{10}	25.33
Tractor plough	Control	1.32×10^{4}	25.33
Tractor plough	Grass	6.0×10^{9}	25.33
Tractor plough	Rice husks	1×10^{100}	25.33
Tractor ripping	Control	5.6×10^{3}	23.66
Tractor ripping	Grass	1×10^{100}	25.33
Tractor ripping	Rice husks	1.04×10^{4}	9.25

Plate 7: Image of incubated Petri dishes showing the growing bacteria colonies (Source: Author)

4.3 Soil health in conservation and conventional tillage systems

These results are based on the objective that sought to evaluate soil health in conservation and conventional tillage treatments. The indicators of soil health in this study were levels of Nitrogen, Phosphorous, Potassium, Soil Organic Carbon and pH. The initial levels measured in March 2018 at the beginning of the experiment were; total nitrogen 0.01%, phosphorous 1.65 $mgkg^{-1}$, potassium 0.54 $cmolkg^{-1}$, organic carbon 1.05%, and soil pH 6.16. These parameters were measured again per the experiment treatments at the end of the first maize cropping season in August 2018 and at the end of the second maize cropping trial in January 2019. This investigation tested the hypothesis that there is no difference in the levels of the soil parameters in conservation and conventional tillage systems.

4.3.1 Effects of tillage and mulch treatments on Nitrogen, Phosphorous, Potassium, Organic carbon and pH at top and sub soil

The levels of the soil chemical characteristic measured at the end of cropping season 1 in August 2018, and at the end of cropping season 2 in January 2019 are presented in Table 20. There were varied changes in the levels of the soil health parameters. Except for organic carbon, the other parameters showed reducing trend from season one to season two. Organic Carbon increased most in No mulch treatments for both conservation and conventional, 33.4% and 30.1% respectively (Table 21). Phosphorous levels dropped substantially in both conservation and conventional tillage treatments where rice husks mulch was applied with 49.5% and 51.7% respectively (Table 21).

Table 20: Levels of Nitrogen (N), Phosphorous (P), Potassium (K), Organic Carbon (OC), and pH, in conservation and conventional tillage treatments

		Total Nitrogen (%)		**Extractable Phosphorous ($mgkg^{-1}$)**		**Exchangeable Potassium ($cmolkg^{-1}$)**		**Organic Carbon (%)**		**Soil pH (1:2.5)**	
Tillage	**Mulch**	**N1**	**N2**	**P1**	**P2**	**K1**	**K2**	**OC1**	**OC2**	**pH1**	**pH2**
Conservation	Grass	0.14	0.09	3.18	2.27	0.93	0.79	1.11	1.37	5.82	5.71
	Rice Husks	0.13	0.09	4.11	2.08	0.90	0.73	1.19	1.34	5.67	5.68
	No Mulch	0.12	0.10	4.82	3.55	0.86	0.78	1.14	1.52	5.71	5.64
Conventional	Grass	0.13	0.09	2.89	2.14	1.01	0.95	1.11	1.44	5.87	5.60
	Rice Husks	0.12	0.09	3.36	1.62	1.05	0.96	1.13	1.44	5.85	5.56
	No Mulch	0.12	0.09	2.65	2.71	1.02	0.89	1.09	1.43	5.79	5.70

Key: Number 1 and 2 following the initials of the soil health parameter represent season. 1 represents end of season one and number 2 end of season 2.

Table 21: Percentage change of soil parameter levels from season one to season two

Tillage	Mulch	Nitrogen (% Change)	Phosphorous (% Change)	Potassium (% Change)	Organic Carbon (% Change)	pH (% Change)
Conservation	Grass Mulch	(-)27.0	(-)28.7	(-)14.9	23.5	(-)1.8
	Rice Husks Mulch	(-)26.0	(-)49.5	(-)18.9	11.6	0.2
	No Mulch	(-)15.9	(-)26.4	(-)9.8	33.4	(-)1.2
Conventional	Grass Mulch	(-)26.6	(-)25.9	(-)5.8	29.8	(-)4.5
	Rice Husks Mulch	(-)16.1	(-)51.7	(-)8.5	27.6	(-)5.0
	No Mulch	(-)19.6	2.1	(-)11.9	30.1	(-)1.6

Table 22: ANOVA results for Total Nitrogen (TN), Phosphorous (P), Potassium (K), Organic Carbon (OC), and pH

Source of variation	TN top	TN sub	P top	P sub	K top	K sub	OC top	OC sub	pH top	pH Sub
Tillage	0.24	0.03*	0.07	0.85	0.09	0.04*	0.28	0.01*	0.60	0.69
Soil cover	0.22	0.27	0.34	0.84	0.87	0.45	0.56	0.09	0.66	0.61
Interaction	0.52	0.67	0.88	0.92	0.43	0.42	0.77	0.32	0.91	0.21
Season (start, season1 and season 2)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Type of soil cover did not significantly affect soil physio-chemical elements while tillage systems significantly ($P < 0.05$) affected the subsoils content of potassium, organic carbon and total nitrogen, although it did not affect the elements at top level of 0 -15cm (Table 22). Hand Basin, a conservation tillage, had the lowest level of potassium at 15 – 30 cm deep, while animal plough had the highest amount of potassium at the same level, and the other tillage types; Animal Ripping, Tractor Plough and Hand Ridge did not vary significantly from each other (Table 23). Tractor Ripping tillage treatment recorded the highest amount of organic carbon and varied significantly from the other tillage types. Hand ridges had the highest amount of total nitrogen although it did not differ significantly from tractor plough, tractor ripping and animal ripping tillage, but it differed significantly from animal plough and hand basin which had the lowest levels of nitrogen (Table 23). An analysis of change across the two cropping seasons comparing the levels of the parameters at the start of the experiment, at the end of cropping season one and at the end of cropping season two showed significant reduction ($p < 0.001$) of the levels of all soil health parameter measured except for organic carbon which showed significant increase. (Table 22).

Table 23: Effects of tillage on the subsoil Potassium, Organic carbon and Nitrogen

Tillage	**N subsoil (%)**	**K subsoil ($cmolkg^{-1}$)**	**OC Subsoil (%)**
Hand Basin	0.08 a	0.30 a	0.78 a
Animal Plough	0.08 a	0.50 b	0.85 a
Animal Ripping	0.09 ab	0.47 b	0.86 a
Tractor Ripping	0.09 ab	0.38 ab	0.97 b
Tractor Plough	0.09 b	0.47 b	0.79 a
Hand Ridge	0.10 b	0.48 b	0.77a

4.3.2 Levels of Nitrogen, Phosphorous, Potassium, Organic carbon and pH for top soil with regard to recommended critical levels for healthy soil

Two-tailed one sample t-test was used to test whether the observed levels of nitrogen, phosphorous, potassium, organic carbon and pH were within the recommended levels for healthy soils to grow maize. Except for Potassium which was much higher than the recommended level, all the other parameters were below the recommended critical values for maize production (Table 24).

Table 24: T-test analysis between the levels of Nitrogen (N), Phosphorus (P), Potassium (K), Organic Carbon (OC) and pH and the respective recommended critical levels

Soil Parameter/Season	**Mean from current study**	**Critical range**	**Standard deviation**	**t -value**	**Test mean**	**P value**
%N1	0.13	0.2-0.4	0.02	-60.70	0.30	< 0.001
%N2	0.10	0.2-0.4	0.01	-116.76	0.30	< 0.001
P1 ($mgkg^{-1}$)	3.50	10.0-15	2.19	-30.20	12.50	< 0.001
P2 ($mgkg^{-1}$)	2.40	10.0-15	2.14	-34.78	12.50	< 0.001
K1 ($CmolKg^{-1}$)	0.96	0.2-0.4	0.28	17.29	0.30	< 0.001
K2 ($CmolKg^{-1}$)	0.85	0.2-0.4	0.31	13.14	0.30	< 0.001
%OC1	1.13	4.0-10	0.16	-274.28	7.00	< 0.001
%OC2	1.42	4.0-10	0.20	-203.30	7.00	< 0.001
pH1	5.79	5.5-7.0	0.35	-9.67	6.25	< 0.001
pH2	5.65	5.5-7.0	0.44	-10.11	6.25	< 0.001

Key: 1 represents end of season sample and 2 represents end of season 2 sample.

4.4 Factors that affect the adoption of Conservation Agriculture among small holder farmers in Kenya and Tanzania

Factors affecting the adoption of conservation agriculture among small holder farmers were identified through a sample of 222 small-scale farmers from both Kenya and Tanzania and are presented in this section. Table 25 details the characteristics of the respondents, from both Morogoro in Tanzania and Bungoma in Kenya samples. Most of the farmers interviewed in both locations were females and majority were within the age range of 36 to 60 years. About three quarters were married and majority of farmers in Tanzania only had primary education, while half of Kenyan farmers had secondary education. More than half the farmers in both countries had other sources of income apart from crop farming. More than half of the farmers in Tanzania had over 20 years of experience in farming. All the interviewed small holder farmers had land which was on flat area or on gentle slopes and practiced rainfed intercropping method of farming.

Table 25: Socio-demographic-farm characteristics of respondents

Characteristics	Categories	Morogoro Tanzania% (n=94)	Bungoma Kenya% (n=128)
Gender	% male	45.7	43.0
	% Female	54.3	57.0
Age (19-78 years)	< 35 year	10.6	18.8
	36-60 years	73.4	63.2
	➢ 60 years	16	18
	Average Age	48	48
Marital Status	Single	8.5	2.3
	Married	74.5	88.3
	Widowed	9.6	8.6
	Divorced/Separated	7.4	0.8
Education	No formal Schooling	6.4	3.9
	Primary Education	85.1	27.3
	O level	6.4	51.6
	A level	1.1	0
	Vocational training	0	4.7
	College	1.1	8.6
	University graduate	0	3.1
	Adult education	0	0.8
Sources of Income	Crop Farming only	38.3	25.8
	Additional sources	61.7	74.2
Farming experience (1-60 years)	1 -10 years	16	31.3
	11 -20 years	32.9	28.9
	above 20 years	51.1	39.8
Land Size (0.1 - 30acres)	1 acre and below	10.6	50
	1.1 - 2.5 acres	33	24.2
	2.6 - 5 acres	38.3	19.6
	above 5 acres	18.1	6.2
Topography of land	Flat land	41.5	61.7
	Gentle slope	56.4	32
	Steep slope	2.1	6.3
Cropping system used	Rainfed intercropping	79.8	79.5
	Rainfed monocropping	19.1	16.5

4.4.1 Awareness and training about Conservation Agriculture practices

Slightly above fifty two percent (52.3%) of all the respondents heard about Conservation Agriculture for the first time from SIMLESA project. However, the number varied significantly between the two countries of study. In Morogoro Tanzania, 83% of the farmers interviewed had not heard about conservation agriculture before the project while only 29.7% of the respondents from Bungoma Kenyan were in that category. Between 68% and 89.8% of the respondents in both countries had received training on the various aspects of conservation agriculture (**Error! Reference source not found.**). The largest group of farmers trained was the Kenyans farmers trained on mulching while the smallest group was Tanzania farmers trained on crop rotation.

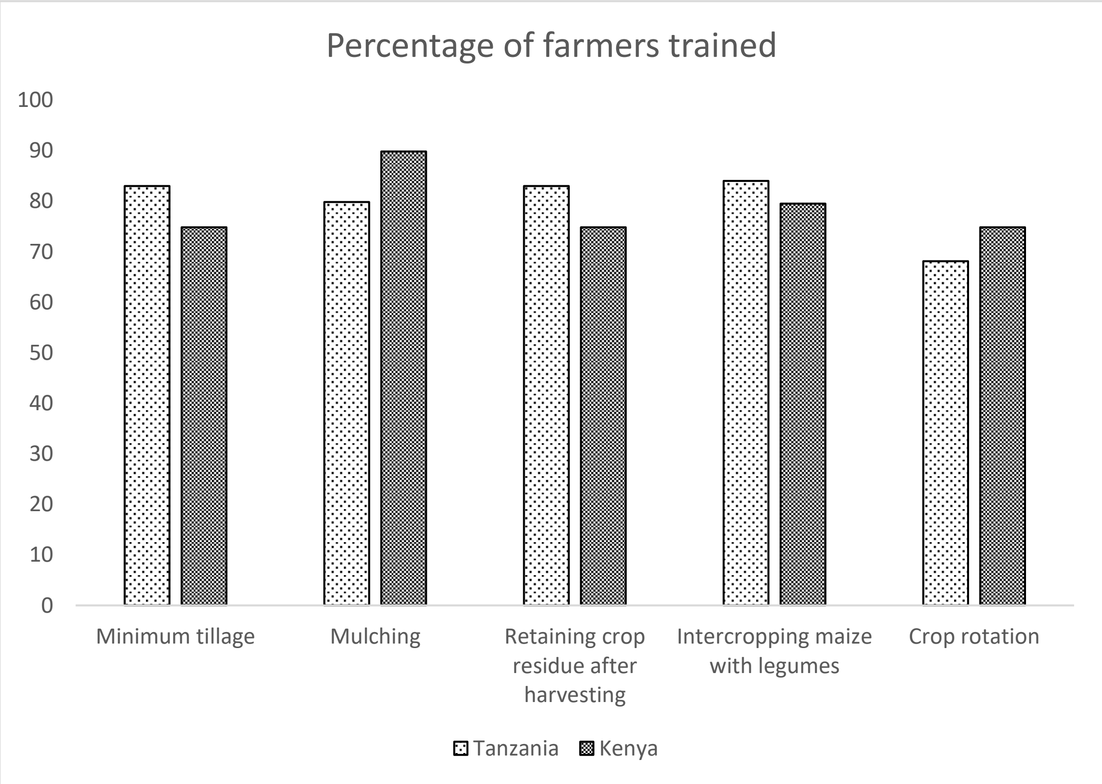

Figure 10: Percentage of Farmers Trained in CA practices

4.4.2 Smallholder farmers perception about conservation agriculture

The study asked the respondents what they think about benefits that accrued from the various practices constituting conservation agriculture. The practices include; reduction of soil disturbance, improving soil structure, increasing soil fertility, protecting soil from erosion and nutrients loss, reduction of labor, enhancing water holding capacity and reduction of surface evaporation, protection of soil from extreme temperatures, increase of crop yield, reduction of greenhouse gases emission into the atmosphere, breaking of pests and disease cycles on the farm, feeding soil organisms, reduction of weed growth. Combining all the responses for all the benefits from all the interviewed farmers, majority of the respondents, 77.9% in Tanzania and 87.5% in Kenya, affirmed that the benefits are tangible in conservation agriculture systems (Figure 11). The details of responses for the specific benefits are outlined in Table 26.

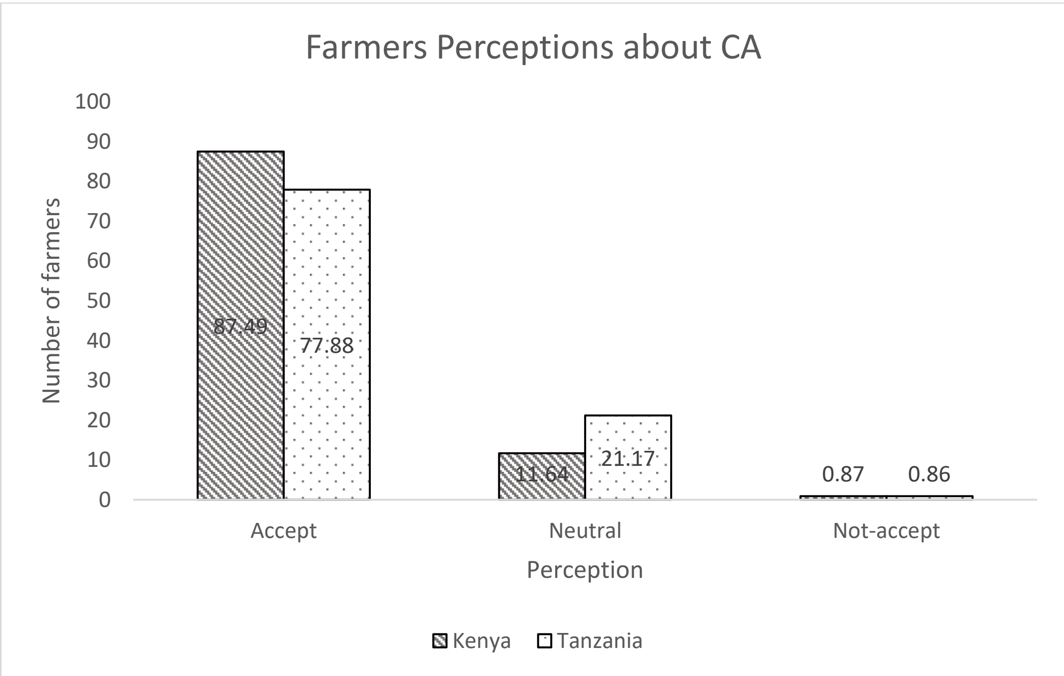

Figure 11: Farmers Perception about Conservation Agriculture benefits

Assessing the perception concerning each potential benefit that farmers accrue from conservation agriculture, the respondents had varying levels of acceptance. Based on their experiences and knowledge, the acceptance rate for all the benefits was high with slight variations between the countries. Table 26 presents the breakdown of the percentage of farmers that agree or disagree with the various benefits.

There was 89.8% and 83.9% of the farmers in Kenya and Tanzania respectively, that agreed that conservation agriculture practices increased crop yield. More Kenyan (95.3%) than Tanzanians (81.7%) have seen improvement of soil structure and protected soil surface from conservation agriculture. With regard to reduced labour as a benefit of conservation agriculture practices, 6.3% Kenyans did not agree to it, but more Tanzanians (79%) had experienced the reduction. None of the Tanzania farmers opposed that conservation agriculture practices for instance direct seed planting reduced soil disturbance. Instead, 21.7% and 14.8% Tanzanians and Kenyans respectively, did not have an opinion about that fact. Crop rotation is one of the main principles of conservation agriculture, relatively less Tanzanians (60.2%) than Kenyans (84.4%) believed that it breaks diseases and pests' cycle. A small percent (16.1) of Tanzania farmers did not have an opinion about the effects of conservation agriculture on weeds. However, 92.2% of Kenyan farmers confirmed that after few years of conservation agriculture establishment, weeds are suppressed.

Table 26: Perceptions about Conservation Agriculture

Conservation Agriculture Practices	% Accept		%Neutral		%Not Accept	
	Kenya	**Tanzania**	**Kenya**	**Tanzania**	**Kenya**	**Tanzania**
CA increases crop yield	89.8	83.9	10.2	16.1	0	0
CA improves soil structure and protects soil surface	95.3	81.7	4.7	18.3	0	0
CA reduces labour	77.3	79	16.4	19	6.3	1
Crop residue enhances moisture retention capacity	91.4	81.7	8.6	17.2	0	1.1
Crop residue retention protects soil from erosion and feeds soil organisms	89.8	82.8	9.4	17.2	0.8	0
Mulches protect soil and reduce surface evaporation	91.4	80.6	8.6	19.4	0	0
No till contributes to reduce greenhouse gases emission	78.9	66.7	21.1	32.3	0	1.1
Direct seed planting increases yield and reduces soil disturbance	84.4	78.3	14.8	21.7	0.8	0
Crop rotation breaks disease cycle	84.4	60.2	15.6	34.4	0	5.4
Cover crop reduces weed growth	92.2	83.9	7	16.1	0.8	0

4.4.3 Farmers willingness to continue with conservation agriculture practices

A few of the farmers in Tanzania (8.5%) that had joined the farmer groups a short while before the study had not started applying conservation agriculture practices, but they pledged to start. Meanwhile, 97.7% and 81.9% of the respondents from Kenya and Tanzania respectively, confirmed that they will continue practicing it. On the same note, 9.6% of Tanzanians and 2.3% of Kenyans were not sure whether they will continue practicing conservation agriculture (Table 27).

Majority of the farmers started applying conservation agriculture on small sections of their land as described in section 4.4.7 below. However, of the farmers that pledged to continue practicing conservation agriculture, 86.7% and 88.3% farmers from Kenya and Tanzania respectively confirmed their plans to increase the size of land they have put under conservation agriculture (Table 27). There was a significant number (13.3%) of Kenyan farmers that could not commit to increasing their land under conservation agriculture since they only accessed small holdings which they had all put under conservation agriculture.

Table 27: Farmers willingness to continue practicing CA

Farmers willingness	Response	Kenya	Tanzania
To continue practicing CA	Willing	97.7%	81.9%
	Not willing	2.3%	18.1%
To increase the size of land under CA	Willing	86.7%	88.3%
	Not willing	13.3%	11.7%

4.4.4 Extension services

Conservation agriculture promotion has been done mostly through reaching out to farmers and creating awareness. Its adoption takes a process and time and farmers need extension support. This study checked with the farmers whether they received extension support and how frequent. The farmers, 91.5% and 85.2% from Tanzania and Kenya respectively, reported that they accessed different forms of extension services. Majority of the Kenyan farmers (45.9%) receive an extension officer on their farm at least once in a cropping season. While majority of farmers from Tanzania (34.1%) receive occasional visit especially when they request the extension officers to visit their farm (Table 28). A small percentage (7.7%) of farmers from Tanzania have never received a visit from an extension officer on their farm but they access extension services either from neighbours' farm visit or project demonstration sites. A few farmers (2.8%) in Kenya only received extension services when local NGOs have an active project running with the farmers.

Table 28: Access to and frequency of extension services

Access to extension service	**Kenya**	**Tanzania**
Access to extension service (yes)	85.2%	91.5%
Access to extension service (No)	14.8%	8.5%
Frequency of on-farm visit		
Once in a month	15.6%	9.9%
Once in a production season	45.9%	15.4%
Frequently	22%	31.9%
Three times during the production season	0.9%	1.1%
Occasionally on request	6.4%	34.1%
Rarely	5.5%	0%
After every two months	0.9%	0%
When NGOs have projects	2.8%	0%
Never	0%	7.7%

4.4.5 Adoption rates of conservation agriculture

The number of farmers that were trained and those that adopted the various conservation agriculture practices varied for each conservation agriculture practice in both Kenya and Tanzania (Table 29). Comparing within the country; 83% of farmers in Tanzania were trained on minimum tillage but only 69.1% had started applying it in their farms by the time of the study. In Kenya, the number of farmers trained on intercropping in (79.5%) was outnumbered by the farmers that were already practicing it. The general trend between the number of farmers trained and those that had started practicing reduced in Tanzania, while for Kenya in was the opposite except for mulching (Table 29).

Table 29: Percentage of farmers trained and applying CA principles

CA Component	**Trained**		**Applying**	
	Tanzania	**Kenya**	**Tanzania**	**Kenya**
Minimum Tillage	83.0%	74.8%	69.1%	75.8%
Mulching	79.8%	89.8%	70.2%	82.5%
Intercropping	84.0%	79.5%	78.7%	87.0%
Crop residue retention	83.0%	74.8%	76.0%	82.1%
Crop rotation	68.1%	74.8%	59.6%	80.0%

4.4.6 Yield factor

Most of the farmers interviewed in both Kenya and Tanzania had recorded harvest of maize before and after adopting conservation agriculture. A paired t-test for both countries proved that maize yield significantly ($P < 0.0001$) (Table 30) increased with the adoption of conservation agriculture. The mean difference between the yield of maize before and after adopting conservation agriculture was -7.0kg and -5.9kg for Kenya and Tanzania respectively. This implies that the yield before farmers started practicing conservation agriculture was less than the yield they harvested after adopting the practices.

Table 30: Paired T-test for yield before and after adopting CA

Country	Mean Difference	Standard Deviation	T value	DF	P value
Kenya	-7.04	9.78	-8.02	123	0.000*
Tanzania	- 5.94	6.83	-7.38	71	0.000*

*Key: * = significant at 0.05 significance level i.e., 95% confidence interval.*

4.4.7 Land factor

Only 11.3% of the farmers interviewed had access to 5 acres (about 2ha) and above (Table 25) at the time of study. The rest of the farmers (88.7) had access to smaller pieces of land. Figure 12 shows that 50% of the interviewed farmers from Kenya carry out their farming activities on land of 1 acre and below in size. In the same category, there is only about 11% of Tanzanians. Majority of farmers (71.3%) in Tanzania access between 1.1 to 5 acres of land while in Kenya, only 43.8% access the same size of land.

Figure 12: Size of land held by farmers in percentage

All the farmers who were already practicing conservation agriculture had only put a small portion of their land under conservation agriculture. Out of a possible 260.8 and 398.6 acres of land held by the interviewed farmers in Kenya and Tanzania respectively, only less than half had been put under conservation agriculture (Table 31). Kenya farmers even with low access to land, had converted 49.4% of it to conservation agriculture. While, Tanzania farmers had only converted 28.9% of their land to conservation agriculture practice.

Table 31: Land under conservation agriculture

	Bungoma, Kenya	**Morogoro, Tanzania**
Total Land accessed	260.8 acres	398.6 acres
Land under CA	128.68	115.5 acres
Proportion of land under CA	49.4%	28.97%

A paired sample t-test for comparing the size of land that a farmer accesses and the size of land they have put on conservation agriculture (Table 31) showed significant difference ($p \leq 0.000$) for both Kenya and Tanzania. The mean differences calculated were 1.03 and 2.77 for Kenya and Tanzania respectively meaning that the land under conservation agriculture is much less than the land farmers access (Table 32).

Table 32: Paired T test results for accessed land and land under CA

Country	**Mean Difference**	**Standard Deviation**	**T value**	**DF**	**P value**
Kenya	1.03	1.81	6.44	127	0.000*
Tanzania	2.76	3.44	7.04	76	0.000*

*Key: * = significant at 0.05 significance level i.e., 95% confidence interval.*

The study found out that farmers in Morogoro rural district and Bungoma county have various forms of land access rights viz inherited from parents, purchased therefore owned, family land which is accessed by all family members but still owned by parents or grandparents and has not been issued for inheritance, rented or leased from an owner, offered by village council to carry out farming activities for a period of time, communal land or borrowed from an owner to use for a period of time. Figure 13 shows the various categories of land tenure for Kenyan and Tanzanian farmers. Inherited land is the most common form of land access by farmers, representing 35% and 37.5% of farmers in Tanzania and Kenya respectively. It is followed closely by purchased land representing about 30% and 31% in Tanzania and Kenya respectively. More farmers in Kenya than in Tanzania accessed family land, and there are more Tanzanians that had rented land compared to Kenyans (Figure 13).

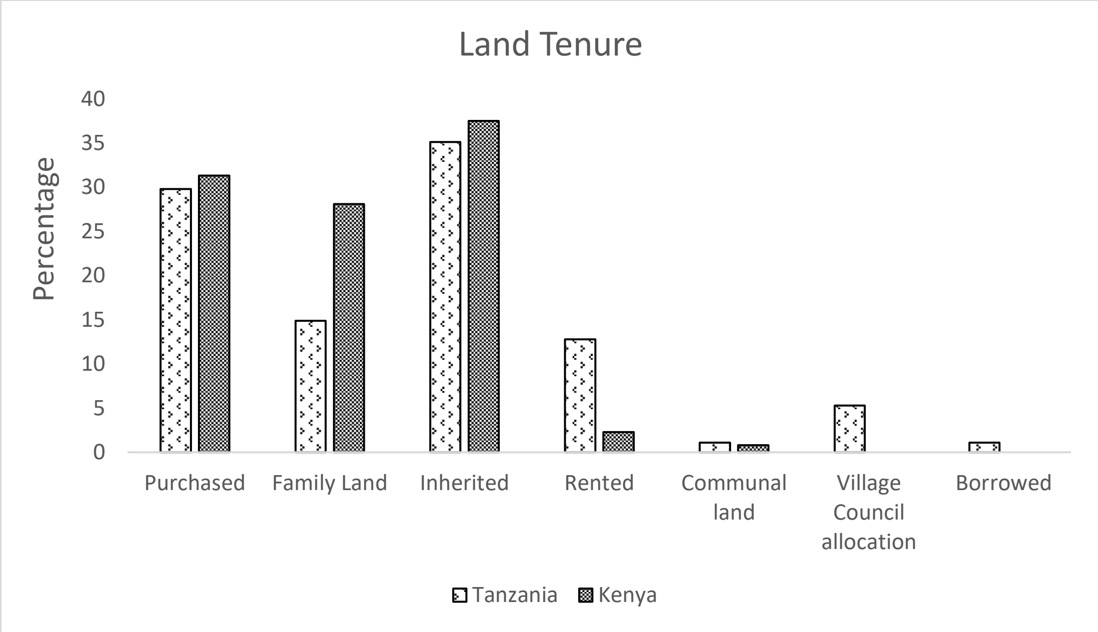

Figure 13: Land tenure systems for land access in Kenya and Tanzania

4.4.8 Social-economic factors

This study found out that farmers choose to adopt or not adopt conservation agriculture based on a number of social-economic factors. Table 33 lists the various social economic factors and the percentage of the farmers that agree with the social economic factor as a hinderance for adoption of CA. Following the scores given by farmers as presented in Table 33, the factors were ranked in order of importance per country.

The social economics issues of importance that hinder adoption of conservation agriculture in Tanzania as ranked in (Table 33) are low level of education, lack of awareness about conservation agriculture, negative attitude towards conservation agriculture, conservativeness of farmers and young farmers lacking land. On the other hand, in Kenya, the issues of importance are low level of education, low-income level, conservativeness of farmers, it takes a long time to establish a conservation agriculture system on a farm and women farmers not participating in decision making regarding adoption of conservation agriculture.

Table 33: Social-economic factors that hinder the adoption of Conservation Agriculture (CA)

	Kenya		**Tanzania**	
	Importance Ranking	**Respondents in Agreement**	**Importance Ranking**	**Respondents in Agreement**
Low level of education that hinder CA adoption	1	64.1%	1	81.7%
Low-income level limits farmers in CA adoption	2	51.6%	7	50.5%
Most farmers are old and conservatives to adopt CA	2	51.6%	4	59.2%
It takes a long time to establish a CA system on a farm	4	49.2%	11	33.3%
Women farmers are not involved in decision making regarding CA adoption	5	48%	8	47.3%

Negative attitude towards CA	6	43.8%	3	63.4%
Lack of awareness of CA existence	7	40.6%	2	66.7%
CA practices are difficult or technical to implement	8	37.5%	10	35.9%
Farmers do not adopt CA because they don't own land	9	37%	6	54.8%
Young farmers have not adopted to CA because they don't have land	9	37%	5	58.7%
CA Practices are expensive	11	34.4%	9	39.8%
Farmers do not practice CA because of a shortage of labor	12	32.8%	12	32.3%

CHAPTER FIVE

DISCUSSION

5.1 Determined maize (*Zea mays*) production

The study hypothesized that the different tillage systems namely; Hand ridges, hand basins, animal plough, animal ripping, tractor plough, and tractor ripping; and the different mulches treatments namely; grass mulch, rice husks mulch and control with no mulch had the same effect on maize biomass. The results however, show that soil cover (mulches) treatments significantly increased the above ground maize biomass, maize grain weight and 100 seeds weight in all three seasons. Where there was no soil cover, the yield reduced significantly in comparison to the plots covered with grass and rice husks mulches (Table 6, Table 7, Table 8, Table 9, Table 11, Table 13). This trend of significant increase in yield on plots covered with mulches as observed in this study are widely recognized in the agronomic and field crops literature, (Thierfelder et al., 2015).

This study has demonstrated an increase of about 18% between the no mulch and mulched plots of maize yield grain and 100 seeds weight. The mean weight of maize grains in the plots with no mulch is significantly lower (6110.8 kg ha^{-1}) than the mulched plots (7400.9 kg ha^{-1}) as shown in Table 7. The plots covered with grass and rice husks mulches did not significantly differ from each other. Therefore, the factor that caused the increase in weight was the soil covering. Soil cover either by crop residue or live crop cover is defined as the main principle of conservation agriculture by (Coll Besa et al., 2010; FAO, 2002; Kassam et al., 2014; LI et al., 2011; Pomeroy & Aljofre, 2012; Vanlauwe et al., 2014). Mulching in this experiment exemplified crop residue retention to cover soil surface.

Agricultural practices that maintain crop residue on the soil surface have been shown to increase maize yield in numerous studies (Bu et al., 2013; Cairns et al., 2012; Naab et al., 2017; Qin et al., 2015; Thierfelder et al., 2015). The yield increase is generally credited to increased water content in the soil due to reduced evaporation. Mulch controls soil erosion by reducing raindrop impact on the soil surface, decreasing the water runoff rate and increasing infiltration of rainwater (Barton et al., 2004; Scopel et al., 2004). It also helps promote stable soil aggregates and provides better protection of soil surface (Hobbs, 2007). The effects of mulches potentially increase crop yields in tropical environments, where there is a risk of drought stress (Bu et al., 2013; Scopel et al., 2004).

A meta-analysis by (Qin et al., 2015) indicated that mulching significantly increased maize yields by up to 60%, compared with no-mulching. These findings are in agreement with this study since mulching increased maize grain yield by 15.4% from 4898.6 kg ha^{-1} to 5790.3 kg ha^{-1} (Table 9). Mulching practices have significant yield advantage, and have been shown by (Qin et al., 2015) to have clear positive and rather consistent effects on maize yield. Statistics (UNESCO, 2009; Van Ittersum et al., 2013), show that rainfed agriculture which covers 80% of the world's cultivated land, and contributes about 60% to the total crop production has been characterized with low productivity due to degraded soil ferity and limited water and nutrient inputs (Qin et al., 2015). Mulching is top on the list of the proposed solutions for increasing 'crop yield per drop and bag'.

The success of conservation agriculture therefore, depends on the ability of farmers to retain crop residues on farm as mulch (Giller et al., 2009). Farmers are not expected to bring organic mulches from ex-situ since that is arguably environmental degradation. The crop residues retained in each season is enough on-site mulch for the following season. However this is challenging because farming systems in east Africa are predominantly mixed crop–livestock systems with low crop productivity and most crop residues are grazed in situ by livestock (Rusinamhodzi et al., 2011). As observed in this study, conservation agriculture increases biomass production which will help address the challenge of sharing the residue between livestock and mulching. These results were also observed by researchers in Tanzania and Zimbabwe (Mtakwa et al., 2019; Pretty et al., 2006; Thierfelder et al., 2015)

Tillage increased above ground biomass during the short rain season two and increased 100 seeds weight in the long rain seasons one and three. Conservation tillage treatments viz; hand basin, animal ripping and tractor ripping increased the yield. (Table 6, Table 11, Table 12, Figure 9). Although the statistical confidence level for tillage treatments was low ($p = 0.061$) according to the result of this study, conservation tillage plots had the highest yields. In terms of ranking the biomass yield; animal ripping, tractor ripping and hand basins all three being conservation tillage plots, had the highest weights of the above ground maize biomass compared to convention tillage practice. The other three, conventional tillage systems, hand ridges, animal and tractor plough have lower biomass (Figure 9).

The observations of this study are similar to trends observed in studies carried out elsewhere. For instance, on-farm and researcher-managed experiments in Ethiopia, Kenya, Tanzania, and Zambia found that conservation tillage practices had higher maize biomass and grain yields as well as improved water use efficiency compared to conventional tillage practices (Rockström et al., 2009). A study in Mexico, (Verhulst et al., 2010) concluded that soil water content during periods of drought resulted in higher average yields for the conservation tillage managed plots over conventional tillage ones. During drier seasons in Malawi, (Ngwira et al., 2012) found that maize yields in systems managed with conservation tillage surpassed yields produced under conventional tillage systems. A different study in Malawi (Ngwira et al., 2013) that used stochastic-dominance, mean-variance analysis, and relative risk-aversion criteria to rank conservational tillage practices and conventional tillage practices for farmers, found that maize grain yields and net returns from minimum and no-tillage treatments exceeded the conventional tillage treatment. Similarly, in China, crop yield in several locations increased due to conservation tillage (Zheng et al., 2014).

The hand ridges (conventional) tillage plots recorded the lowest grain weight (Figure 9) while tractor ripping and hand basin (both conservation) tillage had the highest grain weight in the present study. It is apparent that hand ridges by nature are not able to retain much water due to the slope created by the ridges. Water flows to the lower part of the ridge whereas the maize plants are on the upper part of the ridge. Hand basins by design retain water within the shallow basin, therefore availing more water per maize plant (Yegon et al., 2016). Water is often a major limiting factor for crop production in the tropics, particularly in semi-arid regions.

Crop yields due to tillage systems vary depending on weather conditions in different growing seasons as well as soil characteristics (Rusinamhodzi et al., 2011; Thierfelder & Wall, 2012). This study observed that tillage significantly increased yield in season two which had very low rainfall. The dry weather warranted water supplementing by irrigation.

Interactions between tillage and soil cover treatments increased maize grain weight in the short rain season two and 100 seeds weight in the long rain season three.

Conservation tillage types namely animal ripping, tractor ripping and hand basin with mulches had the highest maize grain and 100 seeds weight (Table 8, Table 10, Table 11, Table 14). This study is in consistence with research results from the tropics which suggested that no-tillage with mulch and herbicide applications maintained and, in some instances, increased maize yields in comparison with conventional tillage (Ngwira et al., 2013; Owenya et al., 2011; Thierfelder & Wall, 2012).

In a long-term effect assessment of no tillage, crop rotation and straw mulching on maize grain yield, (Rusinamhodzi et al., 2011a) found that the mean maize yield was ~1 ton ha^{-1} higher with conservation agriculture practices (with straw mulching) when mean annual precipitation was below 600 mm. In another study, (Pittelkow et al., 2015) reported that crop yields increased by 7.3% under rainfed agriculture in dry climates when no-tillage, straw mulching and crop rotation are implemented together. No-till applied alone (without straw mulching and crop rotation) reduced yields by 11.9%. Also, effects of no-tillage with or without mulching were larger in dry conditions than humid conditions. In consistency with the researchers above, this study has demonstrated about 41% increase from 4021 kg ha^{-1} in conventional tillage to 6792 kg ha^{-1} in conservation tillage combined with mulch (Table 10).

Interactions between the components of conservation agriculture and their effects on crop yields are complex and often site-specific and long-term experiments are necessary to provide a better understanding (Powlson et al., 2006). Nevertheless, the current study, although carried out for only three seasons, has showed significant yield increase from interactions between tillage and soil cover treatments. In theory, reduced tillage and surface cover increase soil water available for crop growth by increasing infiltration and by limiting run-off and evaporation losses. Practically, studies have confirmed that conservation agriculture increases and stabilizes yields and have higher net returns when all its three principles (minimized tillage, soil covering and crop rotation) are applied (Derpsch & Friedrich, 2009; Knowler et al., 2001; Ngwira et al., 2013; Pretty et al., 2006; Thierfelder et al., 2013, 2015). The current study applied minimized tillage and soil cover principles and in three seasons showed significant increase.

As indicated by research, (Adekalu et al., 2007; Findeling et al., 2003; Tarkalson et al., 2006), manipulating tillage and mulch management to improve water infiltration and reduce water loss from the soil surface in crop fields has potential to substantially improve crop yields and soil conditions in the semi-arid tropics.

5.2 Diversity and abundance of soil biodiversity

5.2.1 Diversity and abundance of soil macro-organisms

This study assessed how conservation verses conventional agriculture affects the diversity and abundance of soil macro-organisms. Tillage did not have significant effect on the diversity index of soil macro-organisms but soil cover treatment had significant effect. Season one was the least diverse with D = 0.786, season two was the most diverse with D = 0.281 while season 3, D = 0.331 (Table 18). All the seasons sampling was carried out while the crop was establishing but there were weather differences between the sampling seasons. Season one and three were collected on months that had low rainfall of 29.6 mm and 0.6 mm while season two which has the highest diversity had 299.8 mm. The study focused on macro-organisms that are found on the surface of the soil.

The plots treated with conservation tillage and grass mulch had the highest diversity in all three seasons with D = 0.476, 0.233, and 0.282 respectively (Table 16). Several long-term studies have shown that residue retention in combination with minimum soil disturbance create favourable conditions to promote ecological stability and develop antagonists and predators, contrary to the absence of residue retention (Govaerts et al., 2007). This study, even though relatively short, the high diversity in conservation tillage with grass mulch follows the predicted trend in research. Conservation tillage practices that left crop residue on the soil surface tended to support higher densities of soil macro-organisms (Miyazawa et al., 2002). Differential responses of soil organisms to various tillage systems suggest that populations of selected beneficial macro-organisms can be enhanced via alterations in agronomic practice (Peters et al., 2003; Reeleder et al., 2002).

Out of the total number of 20 species encountered, conservation tillage with grass mulch had the highest representation of 14 species and 893 individuals making 13.7 percent of the total number of individuals encountered in 18 different units. This is in agreement with observation made in Zimbabwe (Mutema et al., 2013), where significantly higher macrofauna population was recorded in conservation agriculture systems than conventional systems. Abundance in conservation agriculture systems increased with increasing amount of crop residues applied in the same study. A study carried out in cotton plantations (Brévault et al., 2007), reported that a substantial portion (34.9%) of the soil macrofauna was collected in the litter. The numbers of individuals were significantly more in the litter from no-till than from conventional tillage. The study also observed that abundance and diversity of soil arthropods were significantly higher in no-till than in conventional tillage plots (+103 and +79%, respectively).

Long-term mixed grass plots on a sandy soil in Canada were found to have substantial populations of macro-organisms but earthworm populations were barely detectable (Reeleder et al., 2006). In this study, a similar trend has been observed since all plots with conservation agriculture treatments had more species and more individuals present. This study also observed that among the conventional agriculture treatments, the ones treated with grass mulch had the highest diversity. Similar to the study in Canada (Reeleder et al., 2006), earthworms represented only about 1% of all the macro-organisms counted in this study. This could be attributed to the fact that earthworms burrow, while the study only focussed on the soil surface. However, a review of several studies, exploring the effects of tillage on earthworms, concluded that deep ploughing and intensive tilling generally reduced earthworm populations in clay loam soils (Chan, 2001). Tillage was the dominant factor affecting earthworm populations (Reeleder et al., 2006). As they burrow through the soil, producing large pores that are important for water flow and retention, aeration, and root development, they help mix organic materials into the soil and aid in aggregate formation (Ruiz et al., 2008).

Across the entire study, ants were the most abundant species constituting 72% of all the individuals encountered. A larger number of ants was found in the no-till plots in a predation experiment (Brévault et al., 2007). It was attributed to the fact that conservation agriculture system led to accumulation of the vegetal biomass in the soil, which increased the numbers of the niches, thus improving the possibility of the biodiversity increment, which contributed to an increase in the richness of the predacious ants. The ants are generalist predators of the small invertebrates and can be found foraging on the soil surface at day and night (Batjes, 2011). Ants are among the most aggressive in using the resources available in the litter and are frequently found in agroecosystems.

About 62% of the beetles and 60% of spiders in this study were found in conservation tillage treatments. Beetles are predators as well as ‘‘litter transformers’’ and spiders are mainly predators. The populations of both are greatly reduced under conventional tillage due to physical disturbance and abrasion from the tillage operation itself (Mashavakure et al., 2019b, 2019a). However, spiders and beetles are active mostly near the soil surface and litter layers, and depend upon the litter or the surface-associated prey as a feed source, therefore reduction of surface residue cover is probably more significant (Wardle, 2002).

Some of the macro organisms sampled are pests for example, Fall Army Worm, *Spodoptera frujiperda* that was recently discovered in Africa and has potential to cause more than 50% damage on maize crop (Kebede, 2018; Muniale et al., 2018). The numbers counted were few since the moth is mostly found inside maize crop and not on the soil surface. However, the larva which is the most commonly seen and most significant for agricultural production could fall from the leaves of a maize crop to the soil surface (Assefa & Ayalew, 2019; Baudron et al., 2019; Harrison et al., 2019; Kansiime et al., 2019).

Soil invertebrates increase soil organic matter by turning plant residues into stable forms. A great deal of soil organic matter is either living soil invertebrates or their faeces and dead bodies (Watt et al., 2006). However, one of the main gaps in agricultural management systems is the lack of awareness and understanding of these organisms and their functions. Hence, inadequate management of soil biological processes to maintain and improve soil productivity. The issue therefore arises as to whether agricultural intensification threatens the numbers of soil organisms and consequently the functions that they perform. An excessive reduction in soil biodiversity, especially the loss of species with key functions, may result in long-term degradation of soil and the loss of agricultural productive capacity (Nardi, 2003; Wardle, 2002). There is need to incorporate management of soil faunal communities as part of farming systems with a broad objective to manage biodiversity for maximum soil resilience. The results of the current study suggest that conservation tillage with mulch can enhance macrofauna biodiversity

In agriculture, the primary goal of the land management practices adopted is to enhance productivity of the desired crop species by manipulating the habitat so as to make it favorable for the growth of those species (Jiménez & Thomas, 2001). However, maintenance of environmental quality is often perceived to be necessary for sustaining the long-term performance of the system (Doran & Zeiss, 2000). This involves ensuring that there are adequate amounts of those soil-associated organisms which are essential for maintaining nutrient cycling and predation of pest organisms which threaten crop productivity (Pretty, 2007). The quality of plant litter is responsible for determining the diversity of soil-associated fauna. Covering soil with grass mulch adds to the organic matter available on the soil, hence the increase of the diversity and abundance of soil macro-organisms. Although soil organisms respond to tillage-induced changes in the soil physical environment, they also have an impact on soil physical and chemical conditions. So they are both affected by tillage and the soil physical/chemical environment and they also have an effect on the soil physical/chemical environment (Barros et al., 2002; Jiménez, 2001).

5.2.2 Diversity and abundance of soil microorganisms

Microbiology is the basis of sustainable agriculture (Tikhonovich & Provorov, 2011). The soil-microbe complex is particularly important with regard to the service it provides for agriculture and natural environments. Understanding the microbial community structure in the soil is important for soil health regeneration process and crops production. At the most basic level, characterizing the microbial community can give an indication of whether the desired microorganisms are present. Although this study did not identify the microbes to species level, it was able to determine the presence of bacteria and fungi in all the sampling units. Neither tillage nor soil cover made a significant difference in the presence or absence or the abundance of the microbes since all the six tillage treatments; Animal Plough, Animal Ripping, Hand Basin, Hand Ridges, Tractor Plough and Tractor ripping; as well as all the three soil cover treatments were represented in the category of too many bacteria colonies that were counted using extrapolation method (Plate 7). Similarly, the treatments that had low ($<2000 \times 10^6$ g^{-1}) numbers of bacteria counted represented five out of six tillage treatments and all the three levels of soil cover treatments. The study did not show significant difference in the numbers of micro-organisms in the conservation and conventional tillage treatments.

The long term study by (Mbuthia et al., 2015) on effects of tillage and no-till on microbial community in cotton production found similar results. Tillage did not have any significant influence on microbial biomass while cover crop had the greatest effect on soil microbial biomass.

The same study (Mbuthia et al., 2015), demonstrated that the conservation agriculture practice of reduced tillage resulted in significant shifts in the microbial community structure. Other studies have also noted that conditions created by reduced tillage practices have been associated to benefits on many soil ecosystem services including enhancement of microbial diversity and abundance (Drijber et al., 2000; Feng et al., 2003). Soil microbial biomass (SMB), often used as an indicator of soil quality and included in certain soil quality indexes, is generally expected to be greater under reduce tillage in most cropping systems (Moore et al., 2000). Reduced tillage is also expected to increase the ratio of fungal to bacterial (Drijber et al., 2000; Helgason et al., 2009). Besides minimal disruption of their hyphal networks, the abundance of fungi has been hypothesized to be greater under reduced tillage mainly because of their cell structural composition comprised of chitin that is more resistant to degradation (Jastrow et al., 2007; Six & Jastrow, 2002; Waring et al., 2013). Bacteria and fungi are important contributors to optimal agricultural waste bioconversion. The microbes use wastes, litter, and crop residues for their own metabolism and finally produce some simple and useful compounds which are important for soil health, plant growth and in overall to keep a good balance of the natural ecosystem (Al-Dhabaan & Bakhali, 2017). Indigenous soil microbiotas depend strongly on microhabitats, microenvironments, and abiotic factors found in soil, with unique soils favouring bacterial communities with specific types of metabolisms and adaptive features for optimal survival and nutrient cycling in that specific ecosystem (Habig et al., 2015).

From numerous site-specific research, it is well known that soil bacterial diversity is immense (Dunbar et al., 2002b; Tringe et al., 2005) and that the composition and diversity of soil bacterial communities can be influenced by a wide range of biotic and abiotic factors (Fierer & Jackson, 2006; Staley & Reysenbach, 2002). However, the soil pH has dramatic importance for below-ground life. One of the most striking pieces of evidence is shown by recent biogeographical studies. For instance, the study by Fierer and Jackson which investigated a data set of 98 soils sampled across the Americas (Fierer & Jackson, 2006). This study showed that temperature, rainfall and latitude had virtually no effect on the diversity and richness of soil microbial communities, whilst soil pH had a major effect, by far the largest amongst the investigated parameters. Bacterial diversity was highest in neutral soils and minimal in acidic soils.

In this study, soil pH measurements taken just before collecting the soil sample for microbiological analysis, showed that this soil was slightly acidic in all the plots with a mean pH of 5.650 (Table 20). Comparing between the conservation and conventional tillage plots in this experiment, there was no significant difference in the diversity and abundance of microbes. However, some plots had lower than the average expected number of bacteria cells per gram of soil viz animal ripping control, animal ripping grass, hand basin grass, hand ridges grass, tractor plough control, tractor ripping control and tractor ripping rice husks. These treatments are mixed with both conservation and conventional tillage.

5.3 Soil health in conservation and conventional tillage systems

In evaluation of soil health for conservation and conventional tillage systems, the levels of Nitrogen, Phosphorous, Potassium, Soil Organic Carbon and pH were measured in three different times during the experiment and their trends observed as presented in section 4.3.

The scoring of soil quality indicators based on site specific factors and their correlation to specific identifiable ecosystem services (in this case maize production and biodiversity conservation) has been proposed as an accepted approach of monitoring and assessing changes in soil functions and quality (Andrews et al., 2004; Sojka et al., 2003; Zobeck et al., 2008). This study will expound on the responses of percentage soil organic carbon, percentage nitrogen, extractable phosphorous, exchangeable potassium and pH to the tillage and soil cover treatments to assess the health of the soil at the study site.

5.3.1 Effects of tillage and soil cover on soil Organic Carbon

The level of organic carbon increased between the seasons $p < 0.001$. Tillage did not affect top soil (0 - 15 cm deep) organic carbon level significantly, but it affected the sub soil level (15 - 30 cm deep) significantly ($p < 0.05$) (Table 22). Overall, there was more organic carbon increase (29.17%) in the plots with conventional tillage including hand ridges, animal plough and tractor plough, as compared to the conservation tillage plot (22.8%) including hand basin, animal ripping and tractor ripping (Table 21). The level of soil organic carbon increased most in the plots that had no mulch treatments. Conservation tillage with no mulch treatment had 33.4% increase between season 1 and 2, followed by conventional tillage with no mulch treatment at 30.1% increase in the level of soil organic carbon (Table 21).

The findings of this study agree with other researchers, (Thierfelder et al., 2013), who reported that conservation agriculture systems as practiced in Zambia generally lead to gradual increase of soil organic carbon. Studies by (Zobeck et al., 2008) on effects of soil management on soil organic carbon showed an increase too. A meta analyses on 67 long – term experiments (West & Post, 2002), concluded that Soil Organic Carbon levels under zero tillage were significantly different from Soil Organic Carbon levels under conventional and reduced tillage, while Soil Organic Carbon levels under conventional and reduced tillage were not significantly different from each other. On the contrary, another study (Alvarez, 2005) found no differences in Soil Organic Carbon between reduced (chisel, disc, and sweep tillage) and zero tillage, whereas conventional tillage (moldboard plow, disc plow) was associated with less Soil Organic Carbon in his compilation of data from 161 sites with contrasting tillage systems (at least whole tillage depth sampled). Conservation agriculture with soybean/maize intercropping maintained higher Soil Organic Carbon compared with conventional tillage in an experiment in Ghana (Naab et al., 2017). Soil organic carbon showed an increasing trend in no till soybean–maize rotation and intercropping compared with conventional tillage plots for a period of four years. Similarly, soil organic carbon in a 12-year study (Kushwa et al., 2016) significantly differed among tillage treatment with the highest level recorded in no-till treatment and lowest level in conventional tillage.

This study observed increasing trend although conventional tillage registered a slightly higher increase. The observed increase in levels of organic carbon in both conservation and conventional tillage may be due to organic residue and biological oxidation of organic matter. The reduced contact between soil and plant residues is considered the primary reason for organic matter accumulation. One of the reasons why organic carbon was higher in conventional tillage (Table 20), is oxidation of organic matter. A less oxidative environment exists under conservation agriculture that under conventional tillage. Therefore, the organic matter originally present below the surface under conservation tillage would not be readily oxidized and changes in organic matter concentrations would occur primarily at or near the soil surface.

It has been concluded by researchers (Angers & Eriksen-Hamel, 2008; Meurer et al., 2018; Powlson et al., 2016), that, significant change in levels of soil organic carbon are observed over a long period of conservation agriculture treatment and this could be the reason why mulch treatments did not increase soil organic matter.

5.3.2 Effects of tillage and soil cover on soil Nitrogen

Nitrogen (N), is an essential macronutrient required in large quantities for plants development. It is the most critical element obtained by plants from the soil and when deficient is a bottleneck in plant growth. In this study, tillage significantly ($p < 0.05$)

affected nitrogen at 15 – 30 cm depth, and levels of nitrogen at top and sub soil level showed significant change ($p < 0.001$) across the seasons, although the change was negative (Table 21 and Table 22). A decrease was observed in all treatments with grass mulch for both conservation and conventional tillage recording the highest decrease of 27% and 26.6% decrease respectively (Table 21). The levels of nitrogen were slightly higher in conservation tillage treatments than in conventional tillage treatments (Table 20). The amount of nitrogen fertilizer applied was similar in all the treatments. This is attributed to greater immobilization of nitrogen fertilizer by the soil microorganisms during the decomposition of fresh plant residues of high carbon/nitrogen ratio. This effect is diminished in subsequent cropping years, the reason also grains yields e.g. maize in many studies remain consistently higher under conservation agriculture than under conventional treatments after several years of cropping at the same Nitrogen rate (Alvarez, 2005; De la Cruz-Barrón et al., 2017; Mbuthia, 2014; Papini et al., 2007).

This study observed net mining of nitrogen between the cropping seasons. All plants need nitrogen to grow but maize particularly needs nitrogen in large quantities for growth and yield (Van Ittersum et al., 2013) and therefore the net mining each growing season. Maize plant removes about 450 grams of nitrogen for every bushel of grain produced, so a 250 bushel per acre yield goal requires 113kg of nitrogen. Furthermore, nitrogen is commonly in limited supply in soil, it must therefore be supplemented at every cropping season (Iqbal et al., 2017). A major factor in successful farming is the farmer's ability to manage nitrogen efficiently, since it is easily lost from the soil and yet it is fairly expensive to supply the large quantity needed by plants. Conservation agriculture holistically provides a good environment for nitrogen cycling, 98 % of the nitrogen in soil is in organic forms therefore it needs soil microorganisms, which thrive in conservation agriculture micro climates, to convert it to mineral forms when they decompose organic matter and fresh plant residues (Moore et al., 2000). This increases the portion of the nitrogen in soil that is available to plants.

Studies regarding tillage and nitrogen have focused on nitrogen as a treatment rather than a variable (Alvarez, 2005; Mbuthia, 2014; Mupangwa et al., 2019; Papini et al., 2007; Qin et al., 2015; Reeleder et al., 2006). This study assessed Nitrogen response on tillage and soil cover treatments. Although a reducing trend was observed, it would take longer trials to understand the relationship between nitrogen responses in relation to other soil chemical properties. For example a study on aggregate associated nitrogen (Mikha & Rice, 2004) showed significant increase in nitrogen after ten years of no-till. A different study, (Papini et al., 2007), observed no difference in residual nitrate nitrogen (NO3-N) in the soil profile among different tillage treatments, except for NH_4-N, which was higher under minimum tillage. The distribution of mobile nutrients, such as NO_3-N and NO_2-N, may be affected by tillage management, due to changes in soil mixing, water content, porosity and organic matter breakdown. Conservation agriculture practices are known to promote soil nitrogen fixation among other benefits (B. Sims et al., 2009). The samples in this study were taken at the end of the cropping season after harvesting, therefore the residual nitrogen in the soil forms the starting point for the next crop.

5.3.3 Effects of tillage and soil cover on soil Phosphorous

Phosphorus (P), is an essential macronutrient required in large quantities for plants development. In this study, phosphorous levels for both top (0 - 15 cm) and sub soil (15 – 30 cm) did not significantly change with tillage or soil cover treatments. However, it changed significantly ($p < 0.001$) between seasons with a reducing trend (Table 21 and Table 22). The levels of phosphorous averaged for conservation tillage treatments (3.92

mg kg^{-1}) was higher than that of conventional tillage treatments (2.97 mg kg^{-1}) (Table 20). In the consecutive season, the levels drastically reduced in plots covered by rice husks mulch, with conventional tillage levels recording the highest drop of 51.7 % and conservation tillage 49.5 % (Table 21). The least reduction was observed in conventional tillage plots that were covered by grass mulch at 25.9 % (Table 21). These results agree with various published studies. For example, the available phosphorus concentration in the soil was significantly influenced by tillage management (Kushwa et al., 2016), and highest available phosphorus concentration (12.8 g kg^{-1}) was recorded in no tillage. Compared to the conventional tillage system, the available phosphorus content in no-tillage treatment was 51 % higher. After 16 years of experimentation, (Wang et al., 2008) the available phosphorous under no till with straw retention was 97.5 % higher than under conventional till with straw removal in the 0- to 5-cm layer, while in the 5- to 10- and 10- to –20-cm soil layers, the phosphorus content was 19.75 and 54.06 %, respectively, lower under no till than under conventional tillage. In the 20- to 30-cm layer, the differences were not significant. After 20 years of no-till experiment, as reported in (Kushwa et al., 2016), extractable P was 42 % greater at 0–5 cm, but 8–18 % lower at 5- to 30-cm depth compared with conventional tillage in a silt loam.

Numerous studies have reported the same trend of higher extractable phosphorous levels in no tillage than in tilled soil in the surface soil layers (Olibone & Rosolem, 2010), and this is due to reduced mixing of the fertilizer phosphorous with the soil, leading to lower phosphorous - fixation. The higher proportion of residues in the surface under no-till system may also increase microbial biomass, leading to higher phosphorous content. In no-tillage system, the availability of surface phosphorus is improved by converting organic phosphorus into available phosphorous. Crops take up phosphorus from deeper part of the soil profile and depositing it on the surface along with crop residues. In conventional tillage systems, phosphorus is usually remixed into the soil profile, whereas in no tillage, it accumulates at the surface (Zibilske et al., 2002).

Phosphorus is an immobile element and usually remains near the site of application unless it is disturbed. But (Roldan et al., 2007) reported that available phosphorous was not affected by tillage system, soil depth or type of crop. Available phosphorus concentration in general was lower at deeper soil layers. The topsoil accumulation of phosphorous in no till systems, is attributed to the limited downward movement of particle bound phosphorous in no-till soils and the upward movement of nutrients from deeper layers through nutrient uptake by roots (Urioste et al., 2006). Consequently, it results in a higher soil test phosphorous level at the soil surface and decrease phosphorous levels deeper in the soil profiles. Improvement in phosphorous could also be attributed to redistribution or ‘‘mining’’ of phosphorous at lower soil depths. In soils under conservation tillage management, extractable phosphorous and other nutrients accumulate in surface layers and decrease with depth (Dıaz-Zorita & Grove, 2002) these nutrient stratification has been attributed to the enrichment provided by the lack of mixing of fertilizers as well as surface crop residue placement in soils under less intensive tillage practices.

Tillage practices were observed to decrease organic carbon and nitrogen contents to a larger extent from the topsoil than from the subsoil, whereas changes for organic phosphates behaved inversely (Bronson et al., 2004). Scientists attributed increases in soil-test-extractable phosphorous under conservation tillage management to organic matter accumulation at the surface, which decreases phosphorous sorption by inorganic colloids (Dıaz-Zorita & Grove, 2002). Greater surface phosphorous concentrations after the adoption of no-till management have been attributed to labile and moderately labile organic forms of phosphorous. Plant residues left on the soil surface release phosphorous and organic acids, which may improve phosphorous availability and fertilizer efficiency (Olibone & Rosolem, 2010).

5.3.4 Effects of tillage and soil cover on soil Potassium

Tillage significantly ($P < 0.05$) affected the level of potassium at 15 – 30 cm depth. The levels also varied significantly between seasons with $P < 0.001$ for top and sub soils (Table 22). The change observed in potassium levels was negative with levels dropping by 18.9% in conservation tillage with rice husks mulch. The change did not show any particular trend but the levels were higher in conventional tillage plots compared to conservation tillage plots (Table 21).

There are several studies that have documented about the stratification of potassium levels along a depth soil profile with a few looking at effects of tillage. In southern China, the highest available potassium (208.87 and 209.38 mg kg^{-1}) content was recorded under the zero tillage treatment (Bai et al., 2008). The available potassium content was lower in the fallow treatment in both no till and conventional tillage compared to where cover crops were planted (Calegari et al., 2013). This could have been attributed to years the land was left fallow without any crops grown which resulted in a lower amount of biomass produced and a reduced potassium bio-cycling. Conservation tillage increased plant available potassium concentrations of top soil (0–30 cm) by 44% in comparison to conventional tillage (Deubel et al., 2011). In another study (Yin & Vyn, 2002) more soil potassium was observed in zero tillage treatment as compared to conventional tillage treatment. The scientists attributed this to higher soil organic carbon level and surface applied potassium fertilizer.

In stratification studies, significantly higher soil potassium concentrations in the surface layer and lower potassium levels at subsurface depths have been observed in no-till compared with soil potassium concentrations at similar depth intervals under moldboard plow or conventional tillage (Borges & Mallarino, 2001; Deubel et al., 2011; Dıaz-Zorita & Grove, 2002; Mallarino & Borges, 2006; Vyn & Janovicek, 2001; Yin & Vyn, 2002). This vertical soil potassium stratification is mainly attributed to limited soil mixing, surface application of potassium fertilizer, deposition of crop residue at the soil surface, and the relative immobility of potassium in soil (Yin & Vyn, 2002). Vertical stratification of soil potassium in no-till or conservation tillage management causes plant potassium uptake to be more dependent on soil potassium and root system characteristics in the surface layer. This may reduce plant potassium uptake, and thus increase the likelihood of potassium deficiency in crop tissues as well as yield loss in growing seasons when drought occurs because soil potassium availability and root growth and activity are more vulnerable to drought in the surface layer than in subsurface layers.(Yin & Vyn, 2002).

In this study, potassium levels at the end of first crop showed significant effect with $p = 0.026$ for top soil. However, the mean comparison showed that tractor ripping and hand basin which are both conservation tillage systems are significantly lower than animal ripping (conservation), and animal ripping (conventional). This does not depict any specific patterns between conservation tillage and conventional. Again, like other soil chemical parameters, to get the exact effects, the experiments need to be long term.

Conservation agriculture itself is a process and its trend in effects on soil quality would be observed over time.

5.3.5 Effects of tillage and soil cover on soil pH

The soils at Morogoro experimental site were slightly acidic. With the different treatment plots ranging from 5.568 to 5.559 (Table 20). That notwithstanding, tillage and soil cover did not show any significant effects during the study period. However, the levels varied significantly ($p < 0.001$) between seasons as shown in (Table 22). Apart from rice husks mulch in conservation tillage that recorded a meager increase in soil pH, the others recorded a reduction (Table 21). Rice husks mulch in conventional tillage reduced the most with 5.0% and the least reduction was observed in no mulch treatment of conservation tillage. Numerically, plots with grass mulch for both conservation and conventional tillage systems had high pH of 5.820 and 5.868 respectively. The rice husks mulch treatments had the least pH at the end of the second crop.

Previous studies had varied results; soil pH varied considerably ($P \leq 0.05$) among tillage practices, with an increase for acidic soils in conservation tillage methods (Asenso et al., 2018). Soil pH increased with soil depth combined with increasing lime contents in both conservation and conventional tillage treatments. Although pH differed significantly between 0 – 15 and 15 – 30 cm soil depth under conservation tillage, the effects of the tillage system on soil pH were negligible (Deubel et al., 2011). Soil pH was significantly lower under conventional tillage than under other tillage systems when averaged across the profile, and was higher at 0 –10 and 10–20 cm, than at 20–30 and 30–40 cm (Papini et al., 2007). The no-till treatment led to significantly *($P <$ 0.01)* decreased pH levels compared to conventional tillage throughout the profile of the alkaline soils (Zibilske et al., 2002). The observation that the surface soil becomes more acidic under no-till than under conventional tillage has been previously reported. Acidification is primarily due to nitrification of surface-applied N fertilizer on soil surface. pH decreased with increasing nitrogen application rates after *5* years of continuous corn (Alvarez, 2005). Surface-applied lime has been shown to be effective in neutralizing soil acidity under no-till, because it creates contact directly with the soil layer where most of the acidity is produced. Soil acidity produced deeper in the soil profile, however, cannot be as effectively neutralized under no-till compared to conventional tillage systems where mixing of the soil and lime occurs.

The acidification observed in the current experiment is attributed to the nitrogen fertilizer added at the planting and booster after one month of the crop. In the rice husks mulch of conservation tillage where a light increase in pH was observed, this could be attributed to the nature of the mulch itself since its water phobic and retains temperature which could have increased the activities of microorganisms (Mtakwa et al., 2019). Decomposition of the mulch can also create a pseudo deficiency of nutrients because the organisms that break it down will consume soil nutrients (Nitrogen, Phosphorous and Potassium) to get energy to break it down. The interest of this study is to use rice husks as soil cover, so fertilizer was applied at the base of each plant. Mulch was applied when the crops were about one month, and top dressing was applied around the plant. In Tanzania, rice husks management is a major problem because they are produced in large quantity as waste products from rice farming. Farmers have an opportunity to used them as mulch although recently rice husks are now being used as fuel for burning bricks.

5.3.6 Soil health parameter levels in comparison to critical levels

Soil health in this study is in relation to the levels of soil Nitrogen, Phosphorous, Potassium, organic carbon and pH. They are macronutrients or elements that are essential to plant growth and are needed in significant amounts (Roy et al., 2006). The nutrient levels measured in the soil were lower than the recommended critic levels (Landon, 2014), except for potassium which is taken luxuriously by maize. Table 20 shows that; Exchangeable potassium was significantly above the critical range $p < 0.001$ because the observed levels ranged from 0.8519 - 0.9622 Cmol Kg^{-1} while the recommended levels range from 0.2-0.4 Cmol Kg^{-1} as shown in Table 3. Healthy levels of potassium in the soil has many benefits, including aiding protein synthesis, stimulating root growth and neutralizing acids. Therefore, it is crucial to most plant functions including stomatal control, the maintenance of turgor pressure and charge balance during selective ion uptake across root membranes. Too much potassium in garden soil is not typically a problem for most plants, they are able to take it up luxuriously without harm (Vyn & Janovicek, 2001). The enhancement of potassium availability in weathered soils is easily achieved, because this nutrient remains stored in soil cation exchange sites. Generally, potassium adsorption in these soils is sufficiently strong to avoid the leaching process and sufficiently weak to supply the nutrient to the soil solution.(Calegari et al., 2013).

Nitrogen was significantly lower ($P < 0.001$) than the recommended level. The recorded levels ranged from 0.09748 % to 0.1252 % against a critical range of 0.2 - 0.4% (Landon, 2014). Nitrogen is a critical macronutrient required by all plant and particularly maize in large quantities. It is a structural component of chlorophyll, nucleic acids (DNA, RNA) and proteins. When it is not sufficient in soil, crops fail. All plants require sufficient supplies of macronutrients for healthy growth, and nitrogen (N) is a nutrient that is commonly in limited supply. Nitrogen deficiency in plants is easily manifested physically by signs of poor growth and discolouration of leaves to pale green and yellow which is a result of insufficiency in chlorophyll formation. Nitrogen deficiency had been observed in many studies, total soil nitrogen concentration was greater in native rangeland than in cropped soils in the entire 30-cm profile (Bronson et al., 2004). Upon introducing conservation agriculture, soil nitrogen losses were reduced, but short-term nitrogen availability was observed due to potential immobilization of nitrogen (Zibilske et al., 2002). Maize nitrogen uptake versus nitrogen susceptible to losses to volatilization, leaching and denitrification was significantly high in cropland (Iqbal et al., 2017).

Extractable phosphorous was significantly low (P < 0.001) with levels from 2.394 mg kg^{-1} to 3.502 mg kg^{-1} against the critical level of 10.0 -15.0 mg kg^{-1}. Phosphorus is a critical macro nutrient required for plant growth. Its deficiency is due to inherent low soil P, high P fixation by Al and Fe oxides and insufficient fertilizer use to replace soil P removed through crop harvests (Kisinyo et al., 2014). Lime, used to correct the acidity in soil, reduces the levels of exchangeable Al3+, Fe3+ and Mn4+ in acid soils and thus reduces P sorption. This makes both the native soil P and applied P fertilizers available for plant uptake (Calba et al., 2006). Soil acidification increases phosphorous deficiency. Limited availability of phosphorous in soil to crops may be dues to deficiency and/or severe phosphorous retention (Batjes, 2011). Under no-till phosphorus (P) accumulates in a few centimetres of the topsoil layer. Where P fertilizers have not been applied, significant surface enrichment in extractable P concentrations occurred under NT, Surface P enrichment could represent P cycled by crops from deeper soil layers and deposited at the soil surface.

Soil organic carbon in this study was significantly low (*P* < 0.001) than the recommended levels. The observed amount ranged from 1.130 % - 1.422 % while the recommended level ranges from 4.0 % to 10%. Soil organic carbon is known to influence a wide range of soil chemical, biological and physical properties and is considered an important indicator of soil quality (Dıaz-Zorita & Grove, 2002). In many farming systems, owing to continuous cropping, soil organic matter contents have diminished to unsustainably low levels and are an important cause of low water and nutrient use efficiency and systems productivity (Montgomery, 2012). Soil Organic Carbon is related to other soil properties that affect soil function and ecosystems services. Organic matter acts as a binding agent for soil particles, helps to hold nutrients and water in soil, and provides the energy, substrates and biological diversity to support biological activity, which affects soil aggregation and water infiltration (Franzluebbers, 2002).

The pH of the soils in the experimental site was lower than the recommended levels with *P* value < 0.001. The observed pH levels ranged from 5.650 - 5.786 and the recommended critical range is between 5.5 and 7.0. This implied that the soils are slightly acidic. Soils are often described as being acid or alkaline or having a certain pH value. The pH scale (from 0 to 14) indicates the degree of acidity based on the concentration of hydrogen ions in a solution. Soils typically fall between pH4 to pH11, with a neutral soil having a pH of 7. Alkaline soils will have a pH greater than 7 while acid soils will have a pH below 7 (Jones et al., 2013). Soil pH is a measure of soil reactivity expressed in a measure of the acidity or alkalinity of the soil. More precisely, it is a measure of hydrogen ion concentration in an aqueous solution and ranges in soils from 3.5 (very acid) to 9.5 (very alkaline). The effect of pH is to remove from the soil or to make available certain ions. Soils with high acidity (<5.5) tend to have toxic amounts of aluminium and manganese. Soils with high alkalinity (>8.5) tend to disperse. Soil organisms are hindered by high acidity, and most agricultural crops do best with mineral soils of pH 6.5 (Jones et al., 2013). The soil pH level recommended for corn is between 5.8 and 6.8 although some recommendations mention up to 7.0 (Calba et al., 2006).

5.3.7 General discussion on soil health in conservation and conventional tillage systems

Soil is a sensitive, living and irreplaceable natural resource linked to everything around us. With increasing demand to grow more food on a resource that only produces 10 cm of fertile soil in 2000 years, it is clear that the responsibility lies with us to look after our soils (Habig et al., 2015). Intensive soil tillage using hand hoes coupled with insufficient organic matter return to the soil are perceived as a major cause of land degradation (Rockström et al., 2009; Wall, 2007b). Conservation agriculture is a sustainable cropping system that may help in reversing soil degradation, stabilizing and possibly increasing yield, and reducing labor time and producing a high net return (Ngwira et al., 2013). Conservation agriculture considerably reduces soil erosion and nutrient losses from the soil into surface waters (Holland, 2004; Tullberg, 2010).

As explained by Prof. Mtakwa (*personal communication*), a soil expert from Sokoine University of Agriculture in Tanzania, the declining trend of soil nutrients observed in this study is not surprising, given that the soil was supplied with a national blanket fertilizer application for Morogoro, and is bound to be less than the actual crop requirement. This is made worse when heavy feeder varieties of maize are used. It is important to point out that the variety used (CP201) needs good/heavy fertilization. This is made worse when the rains are heavy, as was the case in Morogoro during seasons one and three of experimentation. This causes leaching of nutrients. This means that the crop generally mined the soil. When a mulch is incorporated, there is bound to be nutrient pseudo deficiency because nutrients, especially Nitrogen (probably and Phosphorous, as well), is temporarily immobilized by microorganisms that use it as an energy source to break down the tough lignin. This is particularly so for tough mulches such as rice husks that require a lot of energy to break down. Organic carbon is expected to increase due to the input from the mulch.

The level of the nutrients in this study area are not sufficient to support sustainable crop production without supplementation. Soil fertility degradation has been coined as the single most important threat to food security in sub Saharan Africa (Batjes, 2011) (Gichuru et al., 2003) large portion of soils have inherently low fertility. Conventional cropping systems that are based on soil tillage and continuous cycles have negative impact of soil degradation, soil erosion and depletion of soil fertility (Scopel et al., 2004). Insufficient return of organic matter, combined with excessive soil tillage in many cases, increases physical, chemical and biological soil degradation, which is regarded as one of the root causes for declining yields in tropical environments, despite the high yield potential of crop cultivars (Kassam et al., 2009; Stagnari et al., 2009; Thierfelder et al., 2013). According to the soil atlas of Africa, most soils in the sub-Saharan Africa are acidic. Soil acidity and fertility depletion, particularly of nitrogen, phosphorus and low soil organic matter are some of the constraints limiting agricultural production in the high rainfall areas, otherwise suitable for rain-fed crop production in tropical sub-Saharan Africa (Kisinyo et al., 2014).

The soil fertility benefits of conservation agriculture practices are widely recognized in the agronomic and field crops literature (Thierfelder et al., 2015). Researchers (Kassam

& Friedrich, 2009; Thierfelder et al., 2013) concluded that conservation agriculture practices increase soil organic matter contents although variable results have also been found by (Cheesman et al., 2016) and (Powlson et al., 2016). In agricultural systems, maintenance of soil organic matter (SOM) has long been recognized as a strategy to reduce soil degradation (Mikha & Rice, 2004). Soil organic carbon (SOC) is known to influence a wide range of soil chemical, biological and physical properties and is considered an important indicator of soil quality (Dıaz-Zorita & Grove, 2002). In many farming systems, owing to continuous cropping, soil organic matter (SOC) contents have diminished to unsustainably low levels and are an important cause of low water and nutrient use efficiency and systems productivity (Montgomery, 2012).

Excessive nutrient mining over most of Africa is acute, and adequate plant nutrition is often cited as the most limiting factor to crop production in E&S Africa (Wall et al., 2013). To get good response on fertilizer, sufficient amount of soil organic carbon is required. However, soil organic carbon is inherently lacking in the tropics, application of mulch, attained through conservation agriculture, will enhance soil organic carbon since it will increase biomass below and above ground. The adoption of no-till usually leads to the accumulation of soil organic carbon in the surface soil layers (Angers & Eriksen-Hamel, 2008). Soil organic carbon accounts for less than 5% on average of the mass of upper soil layers, and diminishes with depth. According to the CSIRO, in rain-forests or good soils, soil organic carbon can be greater than 10%, while in poorer or heavily exploited soils, levels are likely to be less than 1%. (Young Carbon Farmers, 2019). Many soil chemical and physical properties benefit from having organic matter in soils, with resultant benefits for soil sustainability and crop productivity. (Sawyer, 2008).

Cultivation decreases topsoil contents of organic carbon, total nitrogen, and phosphorous in semiarid regions of the world (Urioste et al., 2006). In general, soil chemical properties of surface layers are more favorable under no-till with crop residue mulching than under plough-till without residue mulching (Papini et al., 2007). However, the relative magnitude of tillage induced differences in soil chemical properties depends on soil, climate and cropping system. The reduction of ploughing depth with shallow tillage or minimum tillage generally leads to an accumulation of organic matter near the soil surface (Papini et al., 2007). With deep inversion tillage, distribution of organic matter is more uniform throughout the ploughed profile (Hernanz et al., 2002) In soils with reduced tillage, an increase in N and P contents along with organic C has been observed (Dıaz-Zorita & Grove, 2002; Zibilske et al., 2002).

Several studies have highlighted significant nutrient losses from African soils (Jones et al., 2013). To give a picture, models estimate that on average, 660 kg Nitrogen ha-1 have been lost during the past 30 years from about 200 million ha of cultivated land in 37 African countries (excluding South Africa). The FAO estimates that Africa is losing 4.4 million t Nitrogen every year from cultivated land. These rates are several times higher than Africa's annual fertilizer consumption of 0.8 million t Nitrogen. Nitrogen loss is driven by cultivation on nutrient-poor soils (Henao & Baanante, 2006). A very large, and potentially the most environmentally damaging loss of nitrogen can happen via the leaching of nitrate. The majority of soil nitrogen is relatively immobile. However, when nitrogen is converted to nitrate it becomes very mobile (Kahl, 2004b).

Soils are natural resources of utmost importance for a number of ecosystem and biosphere processes such as plant production, cycling of organic matter and nutrients, storage of Carbon and water, and release of nitrous oxides, carbon dioxide and methane. Soil degradation, through various processes, is a matter of great concern, since their integrity is absolutely critical to increasing food production, biodiversity conservation and soil health regulation in general among other ecosystem services.

Given the situation in the study area, farmers need to regularly test their soils to get the exact levels of the critical nutrients to be able to take the right amendment measures. The tendency has been for farmers to use compound fertilisers which supply same amount of nutrients every time. For instance, in this soil, it will be fine to use fertilizer which has low potassium for a season. What the farmers need is to use fertiliser with more phosphorous and nitrogen composition. It would also be necessary to apply lime to reduce the soil acidity and increase the pH levels to closer to 7. It is also necessary to enhance the organic carbon by increasing soil organic matter through retention of crop residuals. This is known to enhance fertilizer uptake.

5.4 Factors affecting the adoption of Conservation Agriculture among small holder farmers in Kenya and Tanzania

5.4.1 Adoption rates of conservation agriculture

The study hypothesized that all the farmers that were trained on a particular conservation agriculture practice, would adopt it. The results show that differences between training and adopting for all the practices in both counties of study (Table 29). Therefore, this infers that, although the first phase in the decision-making process regarding adoption, as explained by (Meijer et al., 2015), is the development of knowledge of the innovation; there is something more than just awareness and knowledge that is required for a farmer to adopt conservation agriculture practices.

According to SIMLESA publication (Mulugetta et al., 2011), the project anticipated important challenges such as increasing the availability and affordability of farmer's inputs including fertilizers and herbicides, achieving rational management of crop residues in mixed grazing and cropping farms, and improved weed control in conservation agriculture plots. The respondents raised the same as some of the main challenges they face as they adopt conservation agriculture. This was also echoed by (Coll Besa et al., 2010) as challenges that slow down the adoption of conservation agriculture. The greatest challenge facing wide-scale adoption of conservation agriculture in Africa is the exclusion of the private investors, including entrepreneurial medium-scale farmers, whose critical role and resources, needs also to be unleashed and brought on board (Mkomwa et al., 2011).

There are competing uses of crop residues to keep the soil covered with livestock feeds, fuel, building materials, and handicrafts. Weeds are a real problem especially during the first years of conservation agriculture when there is inadequate soil cover, available mechanical weeding options not conservation agriculture compliant or demand too much labour, soil cover crop seeds are not easily available and the peer pressure that herbicides are not totally safe. Produce prices are usually highly variable, a phenomenon that increases the risks of using expensive inputs. As a result, the African farmer gets punished both ways for over and under production. Risks are aggravated by inadequate development of water resources for supplementary irrigation which leaves most farmers at the mercy of highly irregular rainfall (Mkomwa et al., 2011).

A study in Zimbabwe (Mazvimavi & Twomlow, 2009), found that institutional support and agro-ecological location influenced the adoption intensity of different conservation agriculture practices. Studies in many European countries have shown that conservation agriculture can indeed be very effective in combating soil erosion. However, soil and water conservation do not appear as main drivers in farmers' decisions to shift or not to conservation agriculture. Economic factors tend to be more important, but there are a lot of uncertainties on this domain. (Van den Putte et al., 2010). The major drivers for conservation agriculture adoption globally, as explained by policy analysts (Kassam et al., 2019), are the need to increase input factor productivity, yield and total farm output, improved sustainability of production and farm land, better incomes, timeliness of cropping practices, ease of farming and reduction in drudgery. The improved ecosystem services such as clean water, control of erosion and land degradation, carbon sequestration, cleaner atmosphere and the rehabilitation of degraded agricultural lands come as byproducts of the efforts driven by economic gains.

As observed by SIMLESA project in East Africa, smallholder farmers rarely adopt complete packages of improved technologies despite the biggest final benefit when multiple components are all adopted. More commonly they test and adapt improved practices in a step-wise fashion. Human beings seldom change unless there is an important reason to do so. The problems with current farming systems that suggest the need to embark on the difficult task of knowledge development and system change among millions of smallholder farmers in Eastern and Southern Africa are declining yields and rising costs of production although the causes of these are not always obvious or apparent to many farmers (Wall et al., 2013). Conservation agriculture adopted as a whole, is able to address the vicious cycle of challenges of poor soil health, poor soil water retention, weed management and low yield. However, the process of adoption is gradual starting with reducing tillage, establishing crop cover and finally rotating crops and changing crop associations (Mtakwa et al., 2019). The small-scale farmers require understanding that the process will take a minimum of three years to establish the foundation, as opposed to the expectations of rapid change within one season.

5.4.2 Yield factor

In the SIMLESA project, maize (*Zea mays*) was the main crop being promoted intercropped with legumes. Most of the farmers in Kenya (89.8%) and Tanzania (83.9%) agreed to the fact that conservation agriculture increases yield (Table 26). A comparison between the yield that farmers had recorded before and after adopting aspects of conservation agriculture, using a paired t-test, proved that maize yield increases significantly ($p < 0.0001$) with the adoption of conservation agriculture (Table 30).

Several researchers have highlighted this in various parts of the region and beyond; (Kahimba et al., 2014; Mtakwa et al., 2019; Shetto & Owenya, 2007) showed a significant increase in yield for maize and legumes. In Malawi, similar trends have been observed (Steward et al., 2019). Significant increase in yield was also reported by (Enfors et al., 2011; Hou et al., 2012; Naab et al., 2017; Zheng et al., 2014). Yield in conservation agriculture increases with intensive proper management of other inputs e.g. fertilizer application and pests control especially in the last two years since Fall armyworm (*Spodoptera frugiperda*) was first observed in East Africa (Muniale et al., 2018).

Conservation agriculture was proposed as an adaptation measures for dealing with challenges of climate change (IPCC, 2014). The supporting reasons they gave for investment in improving the diffusion of innovative technologies in agriculture were, use of less labor-intensive technologies in agriculture, increased food-crops production through integrated systems and sustainable agriculture intensification. This was echoed

(Rosenstock et al., 2018) with the quantification that conservation agriculture increases food security by increasing yields at 39.3%, saves labour by 23.9%, saves moisture to alleviate dry spell by 14.8%, increases soil health/fertility by 11.2%, saves time by 3.6%. These are all the aspects that small scale farmers look for as they seek yield improvement.

In mixed crop–livestock systems, there is competition for crop residues between mulching and livestock for feed (Baudron et al., 2012; Chinseu et al., 2019; Giller et al., 2009; Valbuena et al., 2012). Farmers also use this valuable resource for fuel and building. In some areas the residues are burned because there is no associated value involved and termites, especially on loamy and clay soils, make it difficult to retain enough residues (Thierfelder & Wall, 2012). As a result, the soil surface in maize fields is often uncovered and, when exposed to heavy rainfall, build up surface seals and crusts which reduces rainfall infiltration leading to more surface run-off and soil erosion (Jones et al., 2006; Li et al., 2011; Thierfelder & Wall, 2009), and the vicious cycle of low yield results.

As farmers start to adopt conservation agriculture, support across the entire value chain of conservation agriculture is an important aspect of its adoption. A study in Zimbabwe (Mazvimavi & Twomlow, 2009) found that institutional support and agroecological location influences the intensity of adoption of different conservation agriculture practices, and that the practices produce significant yield gains. This made risk-averse farmers to choose conservation agriculture practices over conventional tillage practices.

5.4.3 Land factor

Smallholder farmers in east Africa represent about 80% of farmers (AGRA, 2014; Kassie et al., 2013; Stevenson et al., 2014). Therefore, it was not surprising to find that all the interviewed farmers in this study were smallholders. The size of land holdings among the respondents ranged from 0.1 to 30 acres and varied significantly between the two countries. Kenyan farmers accessed small pieces of land with 50% of them holding less than 1 acre (Figure 12). All the respondents had only put a portion of their land under conservation agriculture. This situation is the recipe for low food production considering household sizes of an average of 6 people (ROK, 2006). The farmers are vulnerable due to the limitation of land size they access and the situation is compounded by the climate changes farming agriculture in general. The rainfall is unpredictable which has created a challenge to farmers since they can’t predict the right timing to prepare land for plant. Timeliness in planting is a major factor in determining production levels of any land. Conservation agriculture allows farmers to prepare land in advance especially because physical manipulation of soil is minimized. The increased capacity to retain moisture in the soil reduces the vulnerability and when little rain comes, it has more impact in conserved tillage than in conventionally tilled land. The farmers with small holdings do not have much choice away from climate smart sustainable intensification which is packaged in conservation agriculture.

Small scale farmers in East Africa have been characterized with gradual response to agricultural innovations. SIMLESA project conducted a survey in the counties of implementation (Mulugetta et al., 2011), and realised that farmers adopt to conservation agriculture stepwise. The nature of the innovation itself however, does not allow for instant adoption of all the three main principles. The first step would be minimizing tillage while controlling weeds using herbicides, then establishing a crop cover at the beginning from crop residue or some form of mulch followed by live crop cover mostly from legumes e.g., Dolichos or Mucuna *ssp.* The last stage is the crop rotation which is season based. Along with the three main principles of conservation agriculture, are other complimentary practices that small-scale farmers adopt for example use of organic manure.

Land factor was vital in adoption of conservation agriculture by small-scale farmers when the issues of access rights are considered. The study found out that farmers in Morogoro rural district and Bungoma county have various forms of land access rights viz inherited from parents, purchased therefore owned, family land which is accessed by all family members but still owned by parents or grandparents and has not been issued for inheritance, rented or leased from an owner, offered by village council to carry out farming activities for a period of time, communal land or borrowed from an owner to use for a period of time. Figure 13 shows the various categories of land tenure in Kenya and Tanzania. Farmers expressed a limitation due to land tenure issues which limit decision making power, particularly on the initial investment. The farmers that inherited and/ or purchased land have more rights on the land since they have full ownership and control. They access it and can decide what exactly they want to do on the land. They can easily make long term investments on the land as well as make decisions to adopt any form of agricultural technology. A research in Haiti, (Smucker et al., 2000) observed that farmers decided to invest on a land based on their perception of long term access to the land. The farmers perceived stability of access is a major factor in adoption of land based agricultural technology. A review on factors that influenced adoption of precision agriculture mentioned land size and land tenure and key factures for consideration by the farmers (Tey & Brindal, 2012).

The other forms of land tenure viz family land, rented land, land allocated by the village council, communal land, and borrowed land, give limiting rights to farmers. During the interview, Mr. Saidi a farmer from Kinongo village in Tomondo ward explained that “*it is difficult to invest in a piece of land owned by someone else, since I only rent it on an annual basis, I can only invest in practices that will give returns within the year*” he further said that “*the owner refused me to use herbicides on claims that it will destroy the land, therefore I just use conventional farming practices*”. These are some of the limitations that come with various land tenure systems. Farmers with access rights but limitations for making some decisions may be aware and knowledgeable about conservation agriculture, but they won't adopt it until they have more rights to a piece of land. Similarly, in Malawi, land control/ownership is a significant factor in small scale farmers getting involved in conservation agriculture (Mlamba, 2010). Land tenure has been established as a major factor in encouraging the investments needed for land management improvements.

In Kenya most of land is owned privately giving farmers more rights to decision making. However, in Tanzania, land is state owned and farmers only lease it. The lease terms are long and operate almost as private ownership, therefore could allow for investments relevant to conservation agriculture ownership. The challenge comes in the communal land where access rights could be revoked at any time. This situation makes farmers hesitant in making any long-term investments. The inter-governmental panel on climate change (IPCC, 2019), listed land tenure as a hinderance for small scale farmers to adopting better cropping, livestock and aquaculture practices, as well as water-saving technologies as approaches for managing the risks and vulnerabilities of climate change through adaptation.

5.4.4 Social economic factor

There are various factors that significantly affect the decision of a farmer to adopt or not to adopt conservation agriculture. A review by researchers, (Knowler & Bradshaw, 2007), categorized the factors as a) Farmer and farm household characteristics, b) Farm biophysical characteristics c) Farm financial/management characteristics and d) exogenous factors.

The social economic factors of importance that hinder the adoption of conservation agriculture among small holder farmers in Kenya are low level of education, low-income level, conservativeness of farmers, the time it takes to establish conservation agriculture system on a farm and lack of involvement of female farmers in decision making regarding adoption of conservation agriculture (Table 33). On the other hand, in Tanzania, the priority social economic issues that hinder adoption of conservation agriculture are low level of education, lack of awareness about conservation agriculture, negative attitude towards conservation agriculture, conservativeness of farmers, and limited access to land by young farmers (Table 33).

Majority of the farmers, 64.1% and 81.7% from Kenya and Tanzania respectively (Table 33), believed that the adoption of conservation agriculture is affected by the level of education. It was ranked number one important social economic issue in both countries (Table 33). Considering that 85.1% of the interviewed farmers in Tanzania and 27.3% in Kenya, had only primary education (Table 25), this claim was further probed. The farmers substantiated that the basic formal education is vital in making a decision and particularly in responding to change. Conservation agriculture induction needs some basic training at first which farmers said can be grasped by farmers even without formal education but understood better over time of practicing and building on experience. The interviewed farmers were members of conservation agriculture groups where they received training as the first step towards its adoption. The small percentage of farmers with no formal education were able to learn, there was no reported challenge attributed to that. However, the training was delivered by trainers who were able to go down to the farmer’s level. Some of the training was practical for example the demonstration sites and farmer field days.

Social networking influences a farmer’s decision on adoption of conservation agriculture. According to Meijer et al. (2015), the position of the farmer in the social networks and the characteristics of the network e.g. the size, connectedness, frequency of interaction, exposure are significant extrinsic factors in the adoption of agricultural innovations by smallholder farmers in sub-Saharan Africa (Meijer et al., 2015). However, to decide whether to participate in the initial step of joining the social groups and acquiring knowledge is determined by the level of education of the farmer.

About 50% of the farmers in Kenya thought that low level of income was the main reason for non-adoption. They further explained that conservation agriculture is, in the long run, cheaper because it reduces labour costs and increases yield, but on face value, it appears as though it is more costly due to the initial inputs at the establishment. Financial viability is an important consideration and may limit interest. Yet a majority of studies suggest that the techniques associated with conservation agriculture have at least modest advantages over conventional practices on this account (Knowler & Bradshaw, 2007; Mupangwa et al., 2017; Mutenje et al., 2019). The training offered to farmers would need to include elaborated information regarding finances to give the farmer an advantage in decision making. Among the challenges that farmers pointed out in their experience with conservation agriculture is the cost of herbicides and pesticides. The situation has now been compounded by Fall Army Warm (*Spodoptera frugiperda*) pest that entered east Africa early 2017 since farmers need to control it by use of pesticides in rapid management to avoid losing the entire crop (Muniale et al., 2018).

Household decision to adopt conservation agriculture was identified as a significant social factor with 47.7% of the farmers arguing that women who received training on conservation agriculture lacked powers to make a decision on its adoption. According to (Mtakwa et al., 2019), the success of conservation agriculture depends not only on whether it can produce high yields or good profits, it also depends on local customs and culture; the way people think of farming and the unwritten rules they follow. Conservation agriculture is, therefore, affected by the different roles and special needs of women and men in the East Africa communities. Decision-making at the household level continues to be male-dominated in all farming-related activities, even in those where women contribute to the majority of the labour. However, joint decision-making is commonplace. A review carried out by (Wekesah et al., 2019) outlines that in sub-Saharan Africa, male-headed households have higher chances of adopting Conservation Agriculture than female-headed households. This is because males have better access to finances, land and other farming inputs. However, (Hove & Gweme, 2018; Kunzekweguta et al., 2017) observed that at the household level, the adoption of Conservation Agriculture transformed intra-household gender relations, decision-making, crop management practices, and increased agency among some women in Zimbabwe. A total of 82.4 % of the respondent s in the study were married, therefore potential for joint decision making and leveraging the strengths of both the females and males in the process of adopting conservation agriculture.

During the formative years of conservation agriculture, herbicides applications is inevitable. Spraying of the herbicides is relatively technical and is an activity usually carried out by men (Mutenje et al., 2019). It takes a male 1 hour and 20 minutes to complete spraying herbicides in 1acre, while weeding the same size of land takes 1 person seven days normally. Conservation agriculture therefore reduces the labour and time significantly (Chinseu et al., 2019; Khurshid et al., 2006; Mtakwa et al., 2019). This changes the dynamics of labour because it relieves the burden of manual weeding from women, who then uses the time for other household or family chores. The economic implication of this significant change between herbicides application and manual weeding is however not apparent to farmers who use family labour since they don't cost it. In East Africa, the retail cost of herbicides enough for one acre is about USD 6, while weeding would cost about USD 21. However, farmers using family labour, which they don't cost, will prefer not to adopt conservation agriculture to avoid spending money on herbicides since it also requires a capital investment of buying a knapsack sprayer.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Although it is generally recognized that benefits of conservation agriculture are not immediate, from the current study the following preliminary conclusions were evident.

1. Mulching increased both the biomass and maize grain yield in all the three seasons. Although the statistical confidence level for tillage treatments was low ($p = 0.061$), there was evidence of increased yields thus suggesting that given few more years the increased benefits will be greater.

2. The study also found that conservation agriculture with grass mulch increased the diversity and abundance of macro-organism when compared to conventional methods but tillage alone did not have significant impact.

3. Both conservation and convention tillage treatments with or without mulch improved soil organic carbon but not Phosphorous, Nitrogen, Potassium and even pH.

4. Yield levels, land size and land access rights are important factors that affect adoption of conservation agriculture. Farmers also consider social economic activities before deciding whether to adopt or not. The factors that ranked top in both countries are education, conservativeness of farmers, low income, gender considerations in decision making, the time it takes to establish conservation

agriculture, lack of awareness and negative attitude about conservation agriculture, and limited access to land by young farmers

6.2 Recommendations

1. Since the study has demonstrated that Conservation agriculture has the potential to increase maize yield, it is recommended that wider scale of research on increase of maize production in conservation agriculture systems be scaled up in a variety of climatic zones. Small scale maize farmers should also be encouraged to cover soils most part of the year since it has immediate positive effects on maize production.

2. The soil biodiversity particularly the macro-organisms increased on mulched areas as observed in the study, it is therefore recommended that small scale farmers create the microclimate for macro-organisms by using grass mulch. Conservation agriculture is therefore recommended as a means to enhance biodiversity in agroecosystems.

3. For farmers to realize immediate benefits of conservation agriculture, it is recommended that they undertake tests to establish the nutrient levels in their soils so that they apply the right amounts of the specific nutrients needed for the specific crops grown.

4. This study found out that farmers adopt aspects of conservation agriculture stepwise. Therefore, continuous extension services is strongly recommended to enhance the adoption of all practices of conservation agriculture. This

requires policy and financial adjustments at central and local level governments.

6.3 Suggestions for further studies

This study has shown that conservation agriculture increases yield and biodiversity. However, it was only carried out in a specific location for only three seasons. Therefore, to get conclusive results on soil health and yield there is need to carry out such a study in different agroecological zones and for a longer time.

This study only assessed above ground macro-organisms therefore there is need to study functional below ground macro-organisms and how tillage and mulching affects their diversity and abundance and their relationships with soil nutrients.

This study was only able to assess the presence of soil microorganisms. Future studies should determine the diversity and abundance of different microorganisms and relate them to soil nutrients over time.

To make more farmers adopt conservation agriculture, there is need for studies beyond production level including support along the entire value chain of the enterprise.

REFERENCES

Adekalu, K. O., Olorunfemi, I. A., & Osunbitan, J. A. (2007). Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. *Bioresource Technology*, *98*(4), 912–917.

Africa Union, A. (2014). *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods Doc. Assembly/Au/2 (Xxiii)*.

AGRA. (2014). *Africa Agriculture Status Report 2014: Climate Change and Smallholder Agriculture in Sub Saharan Africa*. Alliance for Green Revolution Africa (AGRA). https://hdl.handle.net/10568/42343

Al-Dhabaan, F. A. M., & Bakhali, A. H. (2017). Analysis of the bacterial strains using Biolog plates in the contaminated soil from Riyadh community. *Saudi Journal of Biological Sciences*, *24*(4), 901–906. https://doi.org/10.1016/j.sjbs.2016.01.043

Alila, P. O., & Atieno, R. (2006). Agricultural policy in Kenya: Issues and processes. *Nairobi: Institute of Development Studies*.

Alvarez, R. (2005). A review of nitrogen fertilizer and conservation tillage effects on soil organic carbon storage. *Soil Use and Management*, *21*(1), 38–52.

Anderson, T.-H. (2003). Microbial eco-physiological indicators to asses soil quality. *Agriculture, Ecosystems & Environment*, *98*(1–3), 285–293.

Andrews, S. S., Karlen, D. L., & Cambardella, C. A. (2004). The soil management assessment framework. *Soil Science Society of America Journal*, *68*(6), 1945–1962.

Angers, D. A., & Eriksen-Hamel, N. S. (2008). Full-inversion tillage and organic carbon distribution in soil profiles: A meta-analysis. *Soil Science Society of America Journal*, *72*(5), 1370–1374.

Ares, A., Thierfelder, C., Reyes, M., Eash, N. S., & Himmelstein, J. (2015). Global perspectives on conservation agriculture for small households. *Conservation Agriculture in Subsistence Farming: Case Studies from South Asia and Beyond*, 22–54.

Arshad, M. A., & Martin, S. (2002). Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems & Environment*, *88*(2), 153–160.

Asenso, E., Li, J., Hu, L., Issaka, F., Tian, K., Zhang, L., Zhang, L., & Chen, H. (2018). Tillage Effects on Soil Biochemical Properties and Maize Grown in Latosolic Red Soil of Southern China. *Applied and Environmental Soil Science*.

Assefa, F., & Ayalew, D. (2019). Status and control measures of fall armyworm (Spodoptera frugiperda) infestations in maize fields in Ethiopia: A review. *Cogent Food and Agriculture*, *5*(1), Article 1.

Bai, Z. G., Dent, D. L., Olsson, L., & Schaepman, M. E. (2008). Global assessment of land degradation and improvement 1. Identification by remote sensing. *ISRIC-World Soil Information, Wageningen*, *2008*(2), 36–27.

Barrett, C. B. (2010). Measuring food insecurity. *Science, 327*(5967), 825–828.

Barros, E., Pashanasi, B., Constantino, R., & Lavelle, P. (2002). Effects of land-use system on the soil macrofauna in western Brazilian Amazonia. *Biology and Fertility of Soils*, *35*(5), 338–347.

Barton, A. P., Fullen, M. A., Mitchell, D. J., Hocking, T. J., Liu, L., Bo, Z. W., Zheng, Y., & Xia, Z. Y. (2004). Effects of soil conservation measures on erosion rates and crop productivity on subtropical Ultisols in Yunnan Province, China. *Agriculture, Ecosystems & Environment*, *104*(2), 343–357.

Batjes, N. H. (2011). *Global distribution of soil phosphorus retention potential* (p. 42 pp.; 5 fig.; 2 tab.; 106 ref.) [ISRIC Report]. ISRIC-World Soil Information (with dataset).

Batjes, Niels H. (2014). Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, *65*(1), 10–21.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., & Giller, K. E. (2012). Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. *Field Crops Research*, *132*, 117–128.

Baudron, F., Zaman-Allah, M. A., Chaipa, I., Chari, N., & Chinwada, P. (2019). Understanding the factors influencing fall armyworm (Spodoptera frugiperda JE Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. *Crop Protection*, *120*, 141–150.

Blank, D. (2008). A fresh look at life below the surface. *ECHO Development Notes, New Zealand*, *96*, 73–81.

Blein, R. (2013). *Agriculture in Africa: Transformation and outlook*. NEPAD.

Boahen, P., Dartey, B. A., Dogbe, G. D., Boadi, E. A., Triomphe, B., Daamgard-Larsen, S., & Ashburner, J. (2007). Conservation agriculture as practiced in Ghana. *Nairobi: African Conservation Tillage Network/Paris: Agricultural*

Research for Development/Rome: Food and Agriculture Organization of the United Nations.

Boddey, R. M., Jantalia, C. P., Alves, B. J., & Urquiaga, S. (2009). Comments on" no-tillage and soil-profile carbon sequestration: An on-farm assessment". *Soil Science Society of America Journal*, *73*(2), 688.

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution*, *28*(4), 230–238.

Borges, R., & Mallarino, A. P. (2001). Deep banding phosphorus and potassium fertilizers for corn managed with ridge tillage. *Soil Science Society of America Journal*, *65*(2), 376–384.

Brady, N. C., & Weil, R. R. (2007). The colloidal fraction: Seat of soil chemical and physical activity. *Elements of the Nature and Properties of Soil*, 235–286.

Brévault, T., Bikay, S., Maldès, J.-M., & Naudin, K. (2007). Impact of a no-till with mulch soil management strategy on soil macrofauna communities in a cotton cropping system. *Soil and Tillage Research*, *97*(2), 140–149.

Brink, A. B., & Eva, H. D. (2009). Monitoring 25 years of land cover change dynamics in Africa: A sample based remote sensing approach. *Applied Geography*, *29*(4), 501–512.

Bronson, K. F., Zobeck, T. M., Chua, T. T., Acosta-Martinez, V., Van Pelt, R. S., & Booker, J. D. (2004). Carbon and nitrogen pools of southern high plains cropland and grassland soils. *Soil Science Society of America Journal*, *68*(5), 1695–1704.

Bu, L., Liu, J., Zhu, L., Luo, S., Chen, X., Li, S., Hill, R. L., & Zhao, Y. (2013). The effects of mulching on maize growth, yield and water use in a semi-arid region. *Agricultural Water Management*, *123*, 71–78.

Bunderson, W. T., Jere, Z. D., Thierfelder, C., Gama, M., Mwale, B. M., Ng'oma, S. W., Museka, R. M., Paul, J. M., Mbale, B., & Mkandawire, O. (2017). Implementing the principles of conservation agriculture in Malawi: Crop yields and factors affecting adoption. *Conservation Agriculture for Africa*, 75.

Bunge. (2009). Statistical estimation of uncultivated microbial diversity. In *Uncultivated Microorganisms* (pp. 160–178). Springer.

Bunge, J., Willis, A., & Walsh, F. (2014). Estimating the number of species in microbial diversity studies. *Annual Review of Statistics and Its Application*, *1*, 427–445.

Burke, M. B., Lobell, D. B., & Guarino, L. (2009). Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. *Global Environmental Change*, *19*(3), 317–325.

Caamal-Maldonado, J. A., Jiménez-Osornio, J. J., Torres-Barragán, A., & Anaya, A. L. (2001). The use of allelopathic legume cover and mulch species for weed control in cropping systems. *Agronomy Journal*, *93*(1), 27–36.

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security*, *5*(3), 345–360.

Cairns, J. E., Sonder, K., Zaidi, P. H., Verhulst, N., Mahuku, G., Babu, R., Nair, S. K., Das, B., Govaerts, B., & Vinayan, M. T. (2012). Maize production in a changing climate: Impacts, adaptation, and mitigation strategies. In *Advances in agronomy* (Vol. 114, pp. 1–58). Elsevier.

Calba, H., Zonkeng, C., Ngonkeu, E. L. M., Adetimirin, V. O., Mafouasson, H. A., Meka, S. S., & Horst, W. J. (2006). Responses of maize grain yield to changes in acid soil characteristics after soil amendments. *Plant and Soil*, *284*(1–2), 45–57.

Calegari, A., Tiecher, T., Hargrove, W. L., Ralisch, R., Tessier, D., de Tourdonnet, S., de Fátima Guimarães, M., & Dos Santos, D. R. (2013). Long-term effect of different soil management systems and winter crops on soil acidity and vertical distribution of nutrients in a Brazilian Oxisol. *Soil and Tillage Research*, *133*, 32–39.

Convention on Biological Diversity. (2014). *Global Biodiversity Outlook 4. A mid-term assessment of progress towards the implementation of the Strategic Plan for Biodiversity 2011-2020*.

Ceddia, M. G., Bardsley, N. O., Gomez-y-Paloma, S., & Sedlacek, S. (2014). Governance, agricultural intensification, and land sparing in tropical South America. *Proceedings of the National Academy of Sciences*, *111*(20), 7242–7247.

Chamberlin, J., Jayne, T. S., & Headey, D. (2014). Scarcity amidst abundance? Reassessing the potential for cropland expansion in Africa. *Food Policy*, *48*, 51–65.

Chan, K. Y. (2001). An overview of some tillage impacts on earthworm population abundance and diversity—Implications for functioning in soils. *Soil and Tillage Research*, *57*(4), 179–191.

Cheesman, S., Thierfelder, C., Eash, N. S., Kassie, G. T., & Frossard, E. (2016). Soil carbon stocks in conservation agriculture systems of Southern Africa. *Soil and Tillage Research*, *156*, 99–109.

Chikowo, R. (2011). Climatic risk analysis in conservation agriculture in varied biophysical and socio-economic settings of southern Africa. *Food and Agriculture Organisation, Johannesburg, South Africa*, 1–48.

Chinseu, E., Dougill, A., & Stringer, L. (2019). Why do smallholder farmers dis-adopt conservation agriculture? Insights from Malawi. *Land Degradation & Development*, *30*(5), 533–543. https://doi.org/10.1002/ldr.3190

Coleman, D. C., Crossley, D. A., & Hendrix, P. F. (2004). *Fundamentals of soil ecology* (2nd ed.). Academic Press.

Coll Besa, M., Ng'habi, S., Mgeta, E., Efraim, M., & Hamad, M. S. (2010). Barriers and emerging success factors towards effective Conservation Agriculture adoption in the Uluguru Mountains, Tanzania. *CARE International in Tanzania*.

Conceição, P. (2012). Africa human development report 2012-towards a food secure future. *Rapport Technique, United Nations Development Programme-Regional Bureau for Africa, New York, USA*, *23*.

Conceição, Pedro, Levine, S., Lipton, M., & Warren-Rodríguez, A. (2016). Toward a food secure future: Ensuring food security for sustainable human development in Sub-Saharan Africa. *Food Policy*, *60*, 1–9.

Connor, D. J. (2008). Organic agriculture cannot feed the world. *Field Crops Research*, *106*(2), 187.

Crawford, J. W., Harris, J. A., Ritz, K., & Young, I. M. (2005). Towards an evolutionary ecology of life in soil. *Trends in Ecology & Evolution*, *20*(2), 81–87.

Curtis, T. P., & Sloan, W. T. (2005). Exploring microbial diversity–A vast below. *Science*, *309*(5739), 1331–1333.

Dalton, T. J., Yahaya, I., & Naab, J. (2014). Perceptions and performance of conservation agriculture practices in northwestern Ghana. *Agriculture, Ecosystems & Environment*, *187*, 65–71.

De la Cruz-Barrón, M., Cruz-Mendoza, A., Navarro–Noya, Y. E., Ruiz-Valdiviezo, V. M., Ortíz-Gutiérrez, D., Ramírez-Villanueva, D. A., Luna-Guido, M., Thierfelder, C., Wall, P. C., & Verhulst, N. (2017). The bacterial community structure and dynamics of carbon and nitrogen when maize (Zea mays L.) and its neutral detergent fibre were added to soil from Zimbabwe with contrasting management practices. *Microbial Ecology*, *73*(1), 135–152.

DeFries, R., Fanzo, J., Remans, R., Palm, C., Wood, S., & Anderman, T. L. (2015). Metrics for land-scarce agriculture. *Science*, *349*(6245), 238–240.

Derpsch & Friedrich. (2009). Global overview of conservation agriculture no-till adoption. *4th World Congress on Conservation Agriculture*, 4–7.

Derpsch, R. (2008). No-tillage and conservation agriculture: A progress report. In T. Goddard, M. A. Zoebisch, Y. T. Gan, W. Ellis, A. Watson, & S. Sombatpanit, *No-till farming systems.: Vol. Special Publication No. 3* (pp. 7–39). World Association of Soil and Water Conservation, Bangkok.

Derpsch, R., & Friedrich, T. (2010). Global Overview of 44 Conservation Agriculture Adoption. *Conservation Agriculture*, *4*.

Derpsch, R., Friedrich, T., Kassam, A., & Li, H. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering*, *3*(1), 1–25.

Deubel, A., Hofmann, B., & Orzessek, D. (2011). Long-term effects of tillage on stratification and plant availability of phosphate and potassium in a loess chernozem. *Soil and Tillage Research*, *117*, 85–92.

Dixon, J., Gulliver, A., Gibbon, D., & Carloni, A. (2001). *Global farming systems study: Challenges and priorities to 2030. (V. 1): Synthesis and global overview* (Vol. 1–7). FAO.

Dıaz-Zorita, M., & Grove, J. H. (2002). Duration of tillage management affects carbon and phosphorus stratification in phosphatic Paleudalfs. *Soil and Tillage Research*, *66*(2), 165–174.

Doran, J. W., & Zeiss, M. R. (2000). Soil health and sustainability: Managing the biotic component of soil quality. *Applied Soil Ecology*, *15*(1), 3–11.

Drechsel, P., Gyiele, L., Kunze, D., & Cofie, O. (2001). Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. *Ecological Economics*, *38*(2), 251–258.

Drijber, R. A., Doran, J. W., Parkhurst, A. M., & Lyon, D. J. (2000). Changes in soil microbial community structure with tillage under long-term wheat-fallow management. *Soil Biology and Biochemistry*, *32*(10), 1419–1430.

Dunbar, J., Barns, S. M., Ticknor, L. O., & Kuske, C. R. (2002). Empirical and theoretical bacterial diversity in four Arizona soils. *Applied Enviromental Microbiology*, *68*(6), 3035–3045.

E. L. D. Initiative & UNEP. (2015). The economics of land degradation in Africa: Benefits of action outweigh the costs. *The Economics of Land Degradation, Bonn, Germany*.

Edwards, D. (2018). Editorial overview: Feeding the world in a changing climate. *Current Opinion in Plant Biology, England*, *45*, iv–vi. https://doi.org/10.1016/j.pbi.2018.08.004

Enfors, E., Barron, J., Makurira, H., Rockström, J., & Tumbo, S. (2011). Yield and soil system changes from conservation tillage in dryland farming: A case study from North Eastern Tanzania. *Agricultural Water Management*, *98*(11), 1687–1695.

Estefan, G., Sommer, R., & Ryan, J. (2013). Methods of soil, plant, and water analysis. *A Manual for the West Asia and North Africa Region, 3*.

Ethiopian Panel on Climate Change. (2015). *First Assessment Report*, *Working Group II Agriculture and Food Security*. Ethiopian Academy of Sciences.

FAO. (2001). *The economics of conservation agriculture*. Food and Agriculture Organisation.

FAO. (2002). Conservation agriculture: Case studies in Latin America and Africa. *FAO Soils Bulletin, FAO, Rome*, *78*.

FAO. (2008). *Investing in Sustainable Agricultural Intensification. The Role of Conservation Agriculture.* [A framework for action]. Food and Agriculture Organization of the United Nations.

FAO. (2012a). *Towards the Future We Want: End the Hunger and Make the Transition to Sustainable Agriculture and Food Systems* [Report on RIO+20].

FAO. (2012b). *What is CA"? "Principles of CA", "Benefits of CA."*. Food and Agriculture Organisation of United Nations. http://www.fao.org/ag/ca/index.html

FAO. (2013). *Climate-Smart Agriculture; Sourcebook*. http://www.fao.org/3/i3325e/i3325e.pdf

FAO. (2014a). *Building a common vision for sustainable food and agriculture: Principles and approaches.* FAO Rome.

FAO. (2014b). *Review of food and agricultural policies in the United Republic of Tanzania* (MAFAP Country Report Series).

FAO. (2016). *Medium-term prospects for raw materials, horticulture and tropical products*. Trade and Markets Division; Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i5579e.pdf

FAO. (2019). *Soil Properties; Chemical Properties* [Knowledge Sharing]. FAO Soil Portal. http://www.fao.org/soils-portal/soil-survey/soil-classification/numerical-systems/chemical-properties/en/

FAO, F. and A. O. of the U. N. (2010). *Cultivating Sustainable Livelihoods: Socioeconomic Impacts of Conservation Agriculture in Southern Africa.* [Technical Brief No.2]. FAO.

Farooq, M., & Siddique, K. H. (2015). Conservation agriculture: Concepts, brief history, and impacts on agricultural systems. In *Conservation Agriculture* (pp. 3–17). Springer.

Feng, Y., Motta, A. C., Reeves, D. W., Burmester, C. H., Van Santen, E., & Osborne, J. A. (2003). Soil microbial communities under conventional-till and no-till continuous cotton systems. *Soil Biology and Biochemistry*, *35*(12), 1693–1703.

Fierer, N., & Jackson, R. B. (2006). The diversity and biogeography of soil bacterial communities. *Proceedings of the National Academy of Sciences*, *103*(3), 626–631.

Findeling, A., Ruy, S., & Scopel, E. (2003). Modeling the effects of a partial residue mulch on runoff using a physically based approach. *Journal of Hydrology*, *275*(1–2), 49–66.

Fisher, M., Holden, S. T., Thierfelder, C., & Katengeza, S. P. (2018). Awareness and adoption of conservation agriculture in Malawi: What difference can farmer-to-farmer extension make? *International Journal of Agricultural Sustainability*, *16*(3), 310–325.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O’Connell, C., Ray, D. K., & West, P. C. (2011). Solutions for a cultivated planet. *Nature*, *478*(7369), 337.

Fowler, R., & Rockstrom, J. (2001). Conservation tillage for sustainable agriculture: An agrarian revolution gathers momentum in Africa. *Soil and Tillage Research*, *61*(1–2), 93–108.

Franzluebbers, A. J. (2002). Soil organic matter stratification ratio as an indicator of soil quality. *Soil and Tillage Research*, *66*(2), 95–106.

Friedrich, T. (2008). Sustainable production intensification in Africa–a climate change perspective. In A. Bombelli & R. Valentini (Eds.), *Proceedings of the Open Science Conference on "Africa and Carbon Cycle: The CarboAfrica project* (pp. 195–201). FAO Rome, Italy.

Friedrich, T., & Kassam, A. (2009). Adoption of conservation agriculture technologies: Constraints and opportunities. *IVth World Congress on Conservation Agriculture*. IVth World Congress on Conservation Agriculture, New Delhi, India.

Friedrich, T., Kassam, A., & Shaxson, F. (2009). Conservation agriculture. Agriculture for Developing Countries. *Science and Technology Options Assessment (STOA) Project. Karlsruhe, Germany: European Technology Assessment Group*.

Friedrich, Theodor, Derpsch, R., & Kassam, A. (2012). Overview of the global spread of conservation agriculture. *Field Actions Science Reports. The Journal of Field Actions, Special Issue 6*.

Friedrich, Theodor, Derpsch, R., & Kassam, A. (2017). Overview of the global spread of conservation agriculture. In *Sustainable Development of Organic Agriculture* (pp. 75–90). Apple Academic Press.

Garibaldi, L. A., Gemmill-Herren, B., D'Annolfo, R., Graeub, B. E., Cunningham, S. A., & Breeze, T. D. (2017). Farming approaches for greater biodiversity, livelihoods, and food security. *Trends in Ecology & Evolution*, *32*(1), 68–80.

Garnett, T., Appleby, M. C., Balmford, A., Bateman, I. J., Benton, T. G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., & Fraser, D. (2013). Sustainable intensification in agriculture: Premises and policies. *Science*, *341*(6141), 33–34.

Gichuru, M. P., Bationo, A., Bekunda, M. A., Goma, H. C., Mafongoya, P. L., Mugendi, D. N., Murwira, H. K., Nandwa, S. M., Nyathi, P., & Swift, M. J. (2003). *Soil fertility management in Africa: A regional perspective*. Academy Science Publishers (ASP); Centro Internacional de Agricultura ….

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science*, *327*(5967), 812–818.

Govaerts, B., Mezzalama, M., Sayre, K. D., Crossa, J., Nicol, J. M., & Deckers, J. (2006). Long-term consequences of tillage, residue management, and crop rotation on maize/wheat root rot and nematode populations in subtropical highlands. *Applied Soil Ecology*, *32*(3), 305–315.

Govaerts, B., Mezzalama, M., Unno, Y., Sayre, K. D., Luna-Guido, M., Vanherck, K., Dendooven, L., & Deckers, J. (2007). Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. *Applied Soil Ecology*, *37*(1–2), 18–30.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K. D., Dixon, J., & Dendooven, L. (2009). Conservation agriculture and soil carbon sequestration: Between myth and farmer reality. *Critical Reviews in Plant Science*, *28*(3), 97–122.

Grabowski, P. P., & Kerr, J. M. (2014). Resource constraints and partial adoption of conservation agriculture by hand-hoe farmers in Mozambique. *International Journal of Agricultural Sustainability*, *12*(1), 37–53.

Habig, J., Hassen, A. I., & Swart, A. (2015). Application of microbiology in conservation agriculture. In *Conservation Agriculture* (pp. 525–557). Springer.

Haddaway, N. R., Hedlund, K., Jackson, L. E., Kätterer, T., Lugato, E., Thomsen, I. K., Jørgensen, H. B., & Isberg, P.-E. (2017). How does tillage intensity affect soil organic carbon? A systematic review. *Environmental Evidence*, *6*(1), 30.

Haggblade, S & Tembo, G. (2003). *Conservation farming in Zambia: EPTD Discussion Paper No. 108*. IFPRI, Washington D.C.

Haggblade, S., & Tembo, G. (2003b). *Early evidence on conservation farming in Zambia*. International Workshop on Reconciling Rural Poverty and Resource Conservation: Identifying Relationships and Remedies, Cornell University, Ithaca, NY.

Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., & van den Berg, J. (2019). Agro-ecological options for fall armyworm

(Spodoptera frugiperda JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*, *243*, 318–330.

Helgason, B. L., Walley, F. L., & Germida, J. J. (2009). Fungal and bacterial abundance in long-term no-till and intensive-till soils of the Northern Great Plains. *Soil Science Society of America Journal*, *73*(1), 120–127.

Henao, J., & Baanante, C. (2006). Agricultural production and soil nutrient mining in Africa: Implications for resource conservation and policy development. *Bull. International Fertilizer Development Center. Muscle Shoals, Al. USA*, *13*.

Hernanz, J. L., López, R., Navarrete, L., & Sanchez-Giron, V. (2002). Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain. *Soil and Tillage Research*, *66*(2), 129–141.

Herrero, M., Thornton, P. K., Notenbaert, A. M., Wood, S., Msangi, S., Freeman, H. A., Bossio, D., Dixon, J., Peters, M., & van de Steeg, J. (2010). Smart investments in sustainable food production: Revisiting mixed crop-livestock systems. *Science*, *327*(5967), 822–825.

Hinsinger, P., Bengough, A. G., Vetterlein, D., & Young, I. M. (2009). Rhizosphere: Biophysics, biogeochemistry and ecological relevance. *Plant and Soil*, *321*(1–2), 117–152.

Hobbs, P. R. (2007). Conservation agriculture: What is it and why is it important for future sustainable food production? *Journal of Agricultural Science-Cambridge*, *145*(2), 127.

Hobbs, P. R., Sayre, K., & Gupta, R. (2007). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 543–555.

Holland, J. M. (2004). The environmental consequences of adopting conservation tillage in Europe: Reviewing the evidence. *Agriculture, Ecosystems & Environment*, *103*(1), 1–25.

Hou, X. Q., Li, R., Jia, Z. K., Han, Q. F., Yang, B. P., & Nie, J. F. (2012). Effects of rotational tillage practices on soil structure, organic carbon concentration and crop yields in semi-arid areas of northwest China. *Soil Use and Management*, *28*(4), 551–558.

Hove, M., & Gweme, T. (2018). Women’s food security and conservation farming in Zaka District-Zimbabwe. *Journal of Arid Environments*, *149*, 18–29.

Huggins, D. R., & Reganold, J. P. (2008). No-till: How farmers are saving the soil by parking their plows. *Scientific American*, *96*(6), 77–81.

IMF. (2012). *International Jobs Report* (Economist Intelligence Unit).

IMF. (2015). *International Jobs Report* (Economist Intelligence Unit).

IPCC. (2007). *Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland.

IPCC. (2014). *Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (R. K. Pachauri, M. R. Allen, V. R. Barros, J. Broome, W. Cramer, R. Christ, J. A. Church, L. Clarke, Q. Dahe, & P. Dasgupta, Eds.). IPCC, Geneva, Switzerland.

IPCC. (2019). *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems: Summary for Policymakers* [Special Report]. https://www.ipcc.ch/

Iqbal, S., Thierfelder, C., Khan, H. Z., Javeed, H. M. R., Arif, M., & Shehzad, M. (2017). Maximizing maize quality, productivity and profitability through a combined use of compost and nitrogen fertilizer in a semi-arid environment in Pakistan. *Nutrient Cycling in Agroecosystems*, *107*(2), 197–213.

Jastrow, J. D., Amonette, J. E., & Bailey, V. L. (2007). Mechanisms controlling soil carbon turnover and their potential application for enhancing carbon sequestration. *Climatic Change*, *80*(1–2), 5–23.

Jayne, T. S., Meyer, F., & Traub, L. N. (2014). *Africa's Evolving Food Systems: Drivers of change and the scope for influencing them*. IIED Working Paper.

Jeon, S.-O., Bunge, J., Stoeck, T., Barger, K.-A., Hong, S.-H., & Epstein, S. S. (2006). Synthetic statistical approach reveals a high degree of richness of microbial eukaryotes in an anoxic water column. *Applied Enviromental Microbiology*, *72*(10), 6578–6583.

Jiménez, J. J., & Thomas, R. J. (Eds.). (2001). *Nature's plow: Soil macroinvertebrate communities in the neotropical savannas of Colombia*. CIAT. Cali (Columbia).

Johansen, C., Haque, M. E., Bell, R. W., Thierfelder, C., & Esdaile, R. J. (2012). Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. *Field Crops Research*, *132*, 18–32.

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., & Kilasara, M. (Eds.). (2013). *Soil atlas of Africa*. European Union, Luxembourg.

Jones, C. A., Basch, G., Baylis, A. D., Bazzoni, D., Biggs, J., Bradbury, R. B., Chaney, K., Deeks, L. K., Field, R., & Gomez, J. A. (2006). Conservation agriculture in Europe: An approach to sustainable crop production by protecting soil and water? SOWAP. *Jealott's Hill, Bracknell. Jones, GA, Sieving, KE, and Jacobson, SK (2005) Avian Diversity and Functional Insectivory on North-Central Florida Farmlands. Conservation Biology*, *19*, 1234–1245.

Jones, P. G., & Thornton, P. K. (2009). Croppers to livestock keepers: Livelihood transitions to 2050 in Africa due to climate change. *Environmental Science & Policy*, *12*(4), 427–437.

Kahimba, F. C., Mutabazi, K. D., Tumbo, S. D., Masuki, K. F., & Mbungu, W. B. (2014). Adoption and scaling-up of conservation agriculture in Tanzania: Case of Arusha and Dodoma regions. *Natural Resources*, *5*, 161–176. http://dx.doi.org/10.4236/nr.2014.54016

Kahl, H. (2004). Role and importance of nitrogen in your soil. *OrganicNZ Magazine by Soil and Health Association*. https://organicnz.org.nz/magazine-articles/role-importance-nitrogen-soil/

Kansiime, M. K., Mugambi, I., Rwomushana, I., Nunda, W., Lamontagne-Godwin, J., Rware, H., Phiri, N. A., Chipabika, G., Ndlovu, M., & Day, R. (2019). Farmer perception of fall armyworm (Spodoptera frugiderda JE Smith) and farm-level management practices in Zambia. *Pest Management Science*, *75*(10), 2840–2850.

Kanyinga, K. (2009). The legacy of the white highlands: Land rights, ethnicity and the post-2007 election violence in Kenya. *Journal of Contemporary African Studies*, *27*(3), 325–344.

Kassam, A., & Friedrich, T. (2009). Nutrient management in conservation agriculture: A biologically-based approach to sustainable production intensification. *Proceedings of the 7th Conservation Agriculture Conference*, 1–20.

Kassam, A., Friedrich, T., & Derpsch, R. (2019). Global spread of conservation agriculture. *International Journal of Environmental Studies*, *76*(1), 29–51.

Kassam, A., Friedrich, T., Derpsch, R., & Kienzle, J. (2015). Overview of the worldwide spread of conservation agriculture. *Field Actions Science Reports. The Journal of Field Actions*, *8*. http://journals.openedition.org/factsreports/3966

Kassam, Amir, Derpsch, R., & Friedrich, T. (2014). Global achievements in soil and water conservation: The case of Conservation Agriculture. *International Soil and Water Conservation Research*, *2*(1), 5–13.

Kassam, Amir, Friedrich, T., Shaxson, F., & Pretty, J. (2009). The spread of conservation agriculture: Justification, sustainability and uptake. *International Journal of Agricultural Sustainability*, *7*(4), 292–320.

Kassam, Amir, Friedrich, T., Sims, B., & Kienzle, J. (2014). Sustainable intensification and conservation agriculture. *6th World Congress on Conservation Agriculture". Winnipeg Conventional Centre, Manitoba., Winnipeg, Canada*.

Kassam, Amir, Kueneman, E., Kebe, B., Ouedraogo, S., & Youdeowei, A. (2009). *Enhancing crop-livestock systems in conservation agriculture for sustainable production intensification: A farmer discovery process going to scale in*

Burkina Faso. (Vol. 7). Food and Agriculture Organization of the United Nations (FAO).

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, *80*(3), 525–540.

Kaumbutho, P., & Kienzle, J. (Eds.). (2007). *Conservation agriculture as practised in Kenya: Two case studies*. African Conservation Tillage Network; Nairobi, Kenya.

Kaweesa, S., Mkomwa, S., & Loiskandl, W. (2018). Adoption of Conservation Agriculture in Uganda: A Case Study of the Lango Subregion. *Sustainability*, *10*(10), 3375.

Kebede, M. (2018). Out-break, Distribution and Management of fall armyworm, Spodoptera frugiperda JE Smith in Africa: The Status and Prospects. *Academy of Agriculture Journal*, *3*(10).

Khurshid, K., Iqbal, M., Arif, M. S., & Nawaz, A. (2006). Effect of tillage and mulch on soil physical properties and growth of maize. *International Journal of Agriculture and Biology*, *8*(5), 593–596.

Kidane, S. M., Lambert, D. M., Eash, N. S., Roberts, R. K., & Thierfelder, C. (2019). Conservation Agriculture and Maize Production Risk: The Case of Mozambique Smallholders. *Agronomy Journal, American Society of Agronomy, USA*, *111*(3), 1–11. https://doi.org/10.2134/agronj2018.05.0331

Kisinyo, P. O., Othieno, C. O., Gudu, S. O., Okalebo, J. R., Opala, P. A., Ng’etich, W. K., Nyambati, R. O., Ouma, E. O., Agalo, J. J., & Kebeney, S. J. (2014). Immediate and residual effects of lime and phosphorus fertilizer on soil acidity and maize production in western Kenya. *Experimental Agriculture*, *50*(1), 128–143.

Kisinyo, P. O., Othieno, C. O., Gudu, S. O., Okalebo, J. R., Opala, P. A., Ng'Etich, W. K., Nyambati, R. O., Ouma, E. O., Agalo, J. J., & Kebeney, S. J. (2014). Immediate and residual effects of lime and phosphorus fertilizer on soil acidity and maize production in western Kenya. *Experimental Agriculture*, *50*(1), 128–143.

Kladivko, E. J. (2001). Tillage systems and soil ecology. *Soil and Tillage Research*, *61*(1–2), 61–76.

Knowler, Bradshaw, B., & Gordon, D. (2001). *The economics of conservation agriculture*. Land and Water Division, FAO, Rome, Italy.

Knowler, D., & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy*, *32*(1), 25–48.

Kunzekweguta, M., Rich, K. M., & Lyne, M. C. (2017). Factors affecting adoption and intensity of conservation agriculture techniques applied by smallholders in Masvingo district, Zimbabwe. *Agrekon*, *56*(4), 330–346.

Kushwa, V., Hati, K. M., Sinha, N. K., Singh, R. K., Mohanty, M., Somasundaram, J., Jain, R. C., Chaudhary, R. S., Biswas, A. K., & Patra, A. K. (2016). Long-term conservation tillage effect on soil organic carbon and available phosphorous content in vertisols of central India. *Agricultural Research*, *5*(4), 353–361.

Ladha, J. K., Rao, A. N., Raman, A. K., Padre, A. T., Dobermann, A., Gathala, M., Kumar, V., Saharawat, Y., Sharma, S., & Piepho, H. P. (2016). Agronomic improvements can make future cereal systems in South Asia far more productive and result in a lower environmental footprint. *Global Change Biology*, *22*(3), 1054–1074.

Lahmar, R. (2010). Adoption of conservation agriculture in Europe: Lessons of the KASSA project. *Land Use Policy*, *27*(1), 4–10.

Lal, R., & Stewart, B. A. (2019). *Soil Degradation and Restoration in Africa*. CRC Press, Taylor & Francis Group. https://books.google.co.ke/books?id=iH-QwgEACAAJ

Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences*, *108*(9), 3465–3472.

Landon, J. R. (2014). *Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Routledge.

Laurance, W. F., Sayer, J., & Cassman, K. G. (2014). Agricultural expansion and its impacts on tropical nature. *Trends in Ecology & Evolution*, *29*(2), 107–116.

Lavelle, P., & Spain, A. V. (2001). *Soil ecology*. Springer Science & Business Media.

Lesschen, J. P., Stoorvogel, J. J., Smaling, E. M. A., Heuvelink, G. B. M., & Veldkamp, A. (2007). A spatially explicit methodology to quantify soil nutrient balances and their uncertainties at the national level. *Nutrient Cycling in Agroecosystems*, *78*(2), 111–131.

Lewis, L., Onsongo, M., Njapau, H., Schurz-Rogers, H., Luber, G., Kieszak, S., Nyamongo, J., Backer, L., Dahiye, A. M., & Misore, A. (2005). Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in eastern and central Kenya. *Environmental Health Perspectives*, *113*(12), 1763–1767.

Li, L., Huang, G., Zhang, R., Bill, B., Guangdi, L., & Kwong, Y. C. (2011). Benefits of conservation agriculture on soil and water conservation and its progress in China. *Agricultural Sciences in China*, *10*(6), 850–859.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science*, *319*(5863), 607–610.

Löfstrand, F. (2005). *Conservation agriculture in Babati district, Tanzania: Impacts of Conservation agriculture for small-scale farmers and methods for increasing soil fertility* [PhD Thesis]. Sveriges lantbruksuniversitet.

Lugandu, S. (2013). Factors influencing the adoption of conservation agriculture by smallholder farmers in Karatu and Kongwa districts of Tanzania. *REPOA's18thannual Research Workshop Held at the Kunduchi Beach Hotel, Dar Es Salaam, Tanzania*.

Machado, P., Sohi, S. P., & Gaunt, J. L. (2003). Effect of no-tillage on turnover of organic matter in a Rhodic Ferralsol. *Soil Use and Management*, *19*(3), 250–256.

Madejón, E., Moreno, F., Murillo, J. M., & Pelegrín, F. (2007). Soil biochemical response to long-term conservation tillage under semi-arid Mediterranean conditions. *Soil and Tillage Research*, *94*(2), 346–352.

Mallarino, A. P., & Borges, R. (2006). Phosphorus and potassium distribution in soil following long-term deep-band fertilization in different tillage systems. *Soil Science Society of America Journal*, *70*(2), 702–707.

Malley, Z. J., Semoka, J. M. R., Kamasho, J. A., & Kabungo, C. V. (2006). Participatory assessment of soil degradation in the uplands of southwestern Tanzania: Implications for sustainable agriculture and rural livelihoods. *The*

International Journal of Sustainable Development and World Ecology, *13*(3), 183–197.

Mashavakure, N., Mashingaidze, A. B., Musundire, R., Nhamo, N., Gandiwa, E., Thierfelder, C., & Muposhi, V. K. (2019a). Soil dwelling beetle community response to tillage, fertilizer and weeding intensity in a sub-humid environment in Zimbabwe. *Applied Soil Ecology*, *135*, 120–128.

Mashavakure, N., Mashingaidze, A. B., Musundire, R., Nhamo, N., Gandiwa, E., Thierfelder, C., & Muposhi, V. K. (2019b). Spider community shift in response to farming practices in a sub-humid agroecosystem of southern Africa. *Agriculture, Ecosystems & Environment*, *272*, 237–245.

Mazvimavi, K., & Twomlow, S. (2009). Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe. *Agricultural Systems*, *101*(1–2), 20–29.

Mbuthia, L. W. (2014). *Long-Term Impacts of Tillage, Cover Crops, and Nitrogen Rates on Microbial Community Dynamics and Soil Quality Parameters under Continuous Cotton Production in West Tennessee*.

Mbuthia, L. W., Acosta-Martínez, V., DeBruyn, J., Schaeffer, S., Tyler, D., Odoi, E., Mpheshea, M., Walker, F., & Eash, N. (2015). Long term tillage, cover crop, and fertilization effects on microbial community structure, activity: Implications for soil quality. *Soil Biology and Biochemistry*, *89*, 24–34.

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W., & Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International Journal of Agricultural Sustainability*, *13*(1), 40–54.

Meurer, K. H., Haddaway, N. R., Bolinder, M. A., & Kätterer, T. (2018). Tillage intensity affects total SOC stocks in boreo-temperate regions only in the topsoil—A systematic review using an ESM approach. *Earth-Science Reviews*, *177*, 613–622.

Mhlanga, B., Chauhan, B. S., & Thierfelder, C. (2016). Weed management in maize using crop competition: A review. *Crop Protection*, *88*, 28–36.

Mikha, M. M., & Rice, C. W. (2004). Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. *Soil Science Society of America Journal*, *68*(3), 809–816.

Milder, J. C., Majanen, T., & Scherr, S. J. (2011). *Performance and potential of conservation agriculture for climate change adaptation and mitigation in Sub-Saharan Africa*.

Miura, F., Nakamoto, T., Kaneda, S., Okano, S., Nakajima, M., & Murakami, T. (2008). Dynamics of soil biota at different depths under two contrasting tillage practices. *Soil Biology and Biochemistry*, *40*(2), 406–414.

Miyazawa, K., Tsuji, H., Yamagata, M., Nakano, H., & Nakamoto, T. (2002). The effects of cropping systems and fallow managements on microarthropod populations. *Plant Production Science*, *5*(3), 257–265.

Mkomwa S, Shula R, Mzoba H, & Djamen P. (2011). Conservation Agriculture for smallholders in Africa: Lessons, challenges and the vision. *Resilient Food System for a Changing World*, 130–131. www.wcca2011.org

Mkonda, M., & He, X. (2017). Yields of the major food crops: Implications to food security and policy in Tanzania's semi-arid agro-ecological zone. *Sustainability*, *9*(8), 1490.

Mlamba, J. L. (2010). *Factors Affecting Adoption of Conservation Agriculture in Malawi (A Case Study of Salima District)*. 297–298. www.wcca2011.org

Mloza-Banda, H. R., & Nanthambwe, S. J. (2010). Conservation agriculture programmes and projects in Malawi: Impacts and lessons. *Land Resources Conservation Department, Malawi*.

Mmbando, F. E., Wale, E. Z., & Baiyegunhi, L. J. (2015). Welfare impacts of smallholder farmers' participation in maize and pigeonpea markets in Tanzania. *Food Security*, *7*(6), 1211–1224.

Montgomery, D. R. (2012). *Dirt: The erosion of civilizations*. Univ of California Press.

Moore, J. M., Klose, S., & Tabatabai, M. A. (2000). Soil microbial biomass carbon and nitrogen as affected by cropping systems. *Biology and Fertility of Soils*, *31*(3–4), 200–210.

Morris, M., Kelly, V. A., Kopicki, R. J., & Byerlee, D. (2007). *Fertilizer use in African agriculture: Lessons learned and good practice guidelines*. The World Bank.

Mtakwa, P. W., Urio, N. N., Muniale, F. M. W., Mtakwa, A. P., Lal, R., & Singh, B. R. (2019). Conservation Agriculture in Tanzania. In *Soil Degradation and Restoration in Africa* (pp. 195–226). CRC Press, Taylor & Francis Group.

Mulugetta, M., Dimes, J., Dixon, J., Potgieter, A., Prasanna, B., Rodriguez, D., Shiferaw, B., & Wall, P. (2011). The sustainable intensification of maize-legume farming systems in eastern and southern Africa (SIMLESA) program. *Resilient Food System for a Changing World*, 228–229. www.wcca2011.org

Muniale, F. M. W., Mtakwa, P. W., Muyekho, F. N., Baanda, A. S., & Massonga, C. (2018). The role of Conservation Agriculture in management of Fall Army

Worm (Spodoptera frugiperda) in Southern Tanzania. *Making Climate-Smart Agriculture Real in Africa with Conservation Agriculture "Supporting the Malabo Declaration and Agenda 2063". Condensed Papers Book Densed Papers*, 164–167. http://act-africa.org/ACT_Database/ACT_KnowledgeHub/knowledgehub.html

Mupangwa, W., Mutenje, M., Thierfelder, C., & Nyagumbo, I. (2017). Are conservation agriculture (CA) systems productive and profitable options for smallholder farmers in different agro-ecoregions of Zimbabwe? *Renewable Agriculture and Food Systems*, *32*(1), 87–103.

Mupangwa, W., Thierfelder, C., Cheesman, S., Nyagumbo, I., Muoni, T., Mhlanga, B., Mwila, M., Sida, T. S., & Ngwira, A. (2019). Effects of maize residue and mineral nitrogen applications on maize yield in conservation-agriculture-based cropping systems of Southern Africa. *Renewable Agriculture and Food Systems*, 1–14.

Mutema, M., Mafongoya, P. L., Nyagumbo, I., & Chikukura, L. (2013). Effects of crop residues and reduced tillage on macrofauna abundance. *Journal of Organic Systems*, *8*(1), 16-May.

Mutenje, M. J., Farnworth, C. R., Stirling, C., Thierfelder, C., Mupangwa, W., & Nyagumbo, I. (2019). A cost-benefit analysis of climate-smart agriculture options in Southern Africa: Balancing gender and technology. *Ecological Economics*, *163*, 126–137.

Naab, J. B., Mahama, G. Y., Yahaya, I., & Prasad, P. V. V. (2017). Conservation agriculture improves soil quality, crop yield, and incomes of smallholder farmers in North Western Ghana. *Frontiers in Plant Science*, *8*, 996.

Nardi, J. B. (2003). *The world beneath our feet: A guide to life in the soil*. Oxford University Press.

Ngwira, A. R., Thierfelder, C., Eash, N., & Lambert, D. M. (2013). Risk and maize-based cropping systems for smallholder Malawi farmers using conservation agriculture technologies. *Experimental Agriculture*, *49*(4), 483–503.

Ngwira, Amos R., Aune, J. B., & Mkwinda, S. (2012). On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research*, *132*, 149–157.

Ngwira, Amos Robert, Thierfelder, C., & Lambert, D. M. (2013). Conservation agriculture systems for Malawian smallholder farmers: Long-term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems*, *28*(4), 350–363.

Nyende, P., Nyakuni, A., Opio, J. P., & Odogola, W. (2007). Conservation agriculture: A Uganda case study. *Rome: FAO*.

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). *Laboratory methods of soil and plant analysis: A working manual second edition* (2nd ed.). TSBF-CIAT and SACRED Africa, Kenya.

Olibone, D., & Rosolem, C. A. (2010). Phosphate fertilization and phosphorus forms in an Oxisol under no-till. *Scientia Agricola*, *67*(4), 465–471.

Organisation for Economic Co-operation and Developemnt. (2016). *OECD-FAO Agricultural Outlook 2016-2025* (Special Focus: Sub-Saharan Africa). OECD Publishing. http://dx.doi.org/10.1787/agr_outlook-2016-en

Owenya, M. Z., Mariki, W. L., Kienzle, J., Friedrich, T., & Kassam, A. (2011). Conservation agriculture (CA) in Tanzania: The case of the Mwangaza B CA farmer field school (FFS), Rhotia Village, Karatu District, Arusha. *International Journal of Agricultural Sustainability*, *9*(1), 145–152.

Papini, R., Valboa, G., Piovanelli, C., & Brandi, G. (2007). Nitrogen and phosphorous in a loam soil of central Italy as affected by 6 years of different tillage systems. *Soil and Tillage Research*, *92*(1–2), 175–180.

Parry, M., Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.

Peters, R. D., Sturz, A. V., Carter, M. R., & Sanderson, J. B. (2003). Developing disease-suppressive soils through crop rotation and tillage management practices. *Soil and Tillage Research*, *72*(2), 181–192.

Philippot, L., Raaijmakers, J. M., Lemanceau, P., & Van Der Putten, W. H. (2013). Going back to the roots: The microbial ecology of the rhizosphere. *Nature Reviews Microbiology*, *11*(11), 789.

Pittelkow, C. M., Liang, X., Linquist, B. A., Van Groenigen, K. J., Lee, J., Lundy, M. E., Van Gestel, N., Six, J., Venterea, R. T., & van Kessel, C. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, *517*(7534), 365.

Pomeroy, C., & Aljofre, A. (2012). Conservation agriculture as a strategy to cope with climate change in sub-Saharan Africa: The case of Nampula, Mozambique. *Producing and Reproducing Farming Systems. New Modes of Organisation for Sustainable Food Systems of Tomorrow. 10th European IFSA Symposium, Aarhus, Denmark, 1-4 July 2012*.

Powlson, D. S., Stirling, C. M., Thierfelder, C., White, R. P., & Jat, M. L. (2016). Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agriculture, Ecosystems & Environment*, *220*, 164–174.

Powlson, Poulton P, Macdonald AJ, & Bingqiang Z. (2006). *Long-term agricultural experiments: The Necessity for Change and the Need for Continuity*. 18th World Congress of Soil Science, Philadelphia, Pennsylvania, USA.

Pretty, J. (2007). Agricultural sustainability: Concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 447–465.

Pretty, J. (2007c). Agricultural sustainability: Concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 447–465.

Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R. E., Penning de Vries, F. W., & Morison, J. I. (2006). *Resource-conserving agriculture increases yields in developing countries*. ACS Publications.

Qin, W., Hu, C., & Oenema, O. (2015). Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat: A meta-analysis. *Scientific Reports, 5*.

Reeleder, R. D., Miller, J. J., Coelho, B. B., & Roy, R. C. (2006). Impacts of tillage, cover crop, and nitrogen on populations of earthworms, microarthropods, and soil fungi in a cultivated fragile soil. *Applied Soil Ecology*, *33*(3), 243–257.

Reeleder, R. D., Roy, R., & Capell, B. (2002). Seed and Root Rots of Ginseng (Panax quinquefolius L) Caused by Cylindrocarpon destructans and Fusarium spp. *Journal of Ginseng Research*, *26*(3), 151–158.

Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants*, *2*(2), 15221.

Reicosky, D. C., & Saxton, K. E. (2007). *17 Reduced Environmental Emissions and Carbon Sequestration*.

Richards, M., Sapkota, T. B., Stirling, C. M., Thierfelder, C., Verhulst, N., Friedrich, T., & Kienzle, J. (2014). Conservation agriculture: Implementation guidance for policymakers and investors. Climate-Smart Agriculture Practice Brief. CGIAR Research Program on Climate Change. *Agriculture and Food Security (CCAFS), Copenhagen*. https://hdl.handle.net/10568/42431

Rockström, J., Barron, J., & Fox, P. (2002). Rainwater management for increased productivity among small-holder farmers in drought prone environments. *Physics and Chemistry of the Earth, Parts A/B/C*, *27*(11–22), 949–959.

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A. W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J., & Damgaard-Larsen, S. (2009). Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. *Soil and Tillage Research*, *103*(1), 23–32.

ROK. (2004). *Strategy for Revitalising Agriculture 2004-2014, Ministry of Agriculture & Ministry of Livestock and Fisheries Development.*

ROK. (2006). *Annual Progress Report: Investment Programme for Economic Recovery Strategy for Wealth and Employment Creation 2003-2007*.

Roldan, A., Salinas-Garcia, J. R., Alguacil, M. M., & Caravaca, F. (2007). Soil sustainability indicators following conservation tillage practices under subtropical maize and bean crops. *Soil and Tillage Research*, *93*(2), 273–282.

Rosenstock, T., Nowak, A., & Girvetz, E. (Eds.). (2018). Data leaks to help create a climate-smart future. In *The Climate-Smart Agriculture Papers: Investigating the business of a productive, resilient and low emission future* (p. 48). CGIAR.

Roy, R. N., Finck, A., Blair, G. J., & Tandon, H. L. S. (2006). Sources of plant nutrients and soil amendments. *Plant Nutrition for Food Security. FAO Fertilizer and Plant Nutrition Bulletin*, *16*, 93.

Ruiz, N., Lavelle, P., & Jimenez, J. (2008). Soil macrofauna field manual: Technical level. *Food and Agriculture Organisation of the United Nations, Rome,* 101pp. https://doi.org/010057493

Rusinamhodzi, L., Corbeels, M., Van Wijk, M. T., Rufino, M. C., Nyamangara, J., & Giller, K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for Sustainable Development*, *31*(4), 657–673.

Sachs, J., McArthur, J. W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M., & McCord, G. (2004). Ending Africa's poverty trap. *Brookings Papers on Economic Activity*, *2004*(1), 117–240.

Sánchez-Moreno, S. (2016). Biodiversity and soil health: The role of the soil food web in soil fertility and suppressiveness to soil-borne diseases. *X International Symposium on Banana: ISHS-ProMusa Symposium on Agroecological Approaches to Promote Innovative Banana 1196*, 95–104.

Sanginga, N., & Woomer, P. L. (Eds.). (2009). *Integrated soil fertility management in Africa: Principles, practices, and developmental process*. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture.CIAT.

Sapkota, T. B. (2012). Conservation tillage impact on soil aggregation, organic matter turnover and biodiversity. In *Organic fertilisation, soil quality and human health* (pp. 141–160). Springer.

Sawyer, J. (2008). *Importance of Nitrogen in Soils*. Iowa State University. http://www.agronext.iastate.edu/soilfertility/

Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, *5*(1), 014010.

Scopel, E., Da Silva, F. A., Corbeels, M., Affholder, F., & Maraux, F. (2004). Modelling crop residue mulching effects on water use and production of maize under semi-arid and humid tropical conditions. *Agronomie*, *24 (6-7)*, 383–395. https://doi.org/10.1051/agro:2004029

Shaxson, F., & Barber, R. (2003). *Optimizing soil moisture for plant production: The significance of soil porosity*. Rome, Italy: UN-FAO.

Shetto, R., & Owenya, M. (2007). *Conservation agriculture as practised in Tanzania: Three case studies: Arumeru district, Karatu district, Mbeya district*. ACT, FAO, CIRAD, RELMA.

Shrestha, A., Knezevic, S. Z., Roy, R. C., Ball-Coelho, B. R., & Swanton, C. J. (2002). Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. *Weed Research*, *42*(1), 76–87.

Siamachira, J., & Mashango, G. (2015). *Report on the Sustainable Intensification of Maize-Legume Based Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) 5th Annual Review and Planning Meeting*.

Sileshi, G., Akinnifesi, F. K., Ajayi, O. C., & Place, F. (2008). Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. *Plant and Soil*, *307*(1–2), 1–19.

Sims, B., Friedrich, T., Kassam, A., & Kienzle, J. (2009). Agroforestry and conservation agriculture: Complementary practices for sustainable development. *Agriculture for Development*, *8*, 13–18.

Sims, B. G., Thierfelder, C., Kienzle, J., Friedrich, T., & Kassam, A. (2012). Development of the conservation agriculture equipment industry in sub-Saharan Africa. *Applied Engineering in Agriculture*, *28*(6), 813–823.

Six, J., & Jastrow, J. D. (2002). Organic matter turnover. *Encyclopedia of Soil Science*, 936–942.

Smucker, G. R., White, T. A., & Bannister, M. (2000). *Land tenure and the adoption of agricultural technology in Haiti* (CAPRi Working Paper 06) [Working Paper No. 6]. IFPRI. http://purl.umn.edu/50042

Sojka, R. E., Upchurch, D. R., & Borlaug, N. E. (2003). Quality soil management or soil quality management: Performance versus semantics. *Advances in Agronomy*, *79*, 1–68.

Stagnari, F., Ramazzotti, S., & Pisante, M. (2009). Conservation agriculture: A different approach for crop production through sustainable soil and water management: a review. In *Organic farming, pest control and remediation of soil pollutants* (pp. 55–83). Springer.

Staley, J. T., & Reysenbach, A.-L. (2002). *Biodiversity of microbial life*. Wiley.

Stevenson, J. R., Serraj, R., & Cassman, K. G. (2014). *Evaluating conservation agriculture for small-scale farmers in Sub-Saharan Africa and South Asia*. Elsevier.

Steward, P. R., Thierfelder, C., Dougill, A. J., & Ligowe, I. (2019). Conservation agriculture enhances resistance of maize to climate stress in a Malawian medium-term trial. *Agriculture, Ecosystems & Environment*, *277*, 95–104.

Swanepoel, C. M., Swanepoel, L. H., & Smith, H. J. (2018). A review of conservation agriculture research in South Africa. *South African Journal of Plant and Soil*, *35*(4), 297–306. https://doi.org/10.1080/02571862.2017.1390615

Tarkalson, D. D., Hergert, G. W., & Cassman, K. G. (2006). Long-term effects of tillage on soil chemical properties and grain yields of a dryland winter wheat–sorghum/corn–fallow rotation in the Great Plains. *Agronomy Journal*, *98*(1), 26–33.

Tey, Y. S., & Brindal, M. (2012). Factors influencing the adoption of precision agricultural technologies: A review for policy implications. *Precision Agriculture*, *13*(6), 713–730.

Thierfelder, C., & Wall, P. C. (2012). Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. *Soil Use and Management*, *28*(2), 209–220.

Thierfelder, Christian, Cheesman, S., & Rusinamhodzi, L. (2013). Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa. *International Journal of Agricultural Sustainability*, *11*(2), 108–124.

Thierfelder, Christian, Matemba-Mutasa, R., & Rusinamhodzi, L. (2015). Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. *Soil and Tillage Research*, *146*, 230–242.

Thierfelder, Christian, Mwila, M., & Rusinamhodzi, L. (2013). Conservation agriculture in eastern and southern provinces of Zambia: Long-term effects on soil quality and maize productivity. *Soil and Tillage Research*, *126*, 246–258.

Thierfelder, Christian, Rusinamhodzi, L., Ngwira, A. R., Mupangwa, W., Nyagumbo, I., Kassie, G. T., & Cairns, J. E. (2015). Conservation agriculture in Southern

Africa: Advances in knowledge. *Renewable Agriculture and Food Systems*, *30*(4), 328–348.

Thierfelder, Christian, & Wall, P. C. (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil and Tillage Research*, *105*(2), 217–227.

Tikhonovich, I. A., & Provorov, N. A. (2011). Microbiology is the basis of sustainable agriculture: An opinion. *Annals of Applied Biology*, *159*(2), 155–168.

Tittonell, P. (2014). Ecological intensification of agriculture—Sustainable by nature. *Current Opinion in Environmental Sustainability*, *8*, 53–61.

Tittonell, P., & Giller, K. E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, *143*, 76–90.

Tringe, S. G., Von Mering, C., Kobayashi, A., Salamov, A. A., Chen, K., Chang, H. W., Podar, M., Short, J. M., Mathur, E. J., & Detter, J. C. (2005). Comparative metagenomics of microbial communities. *Science*, *308*(5721), 554–557.

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J., & Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation*, *151*(1), 53–59.

Tullberg, J. (2010). Tillage, traffic and sustainability—A challenge for ISTRO. *Soil and Tillage Research*, *111*(1), 26–32.

Umar, B. B. (2011). Integrating Conservation Agriculture with trees: Trends and possibilities among Smallholder Zambian farmers. *5th World Congress on Conservation Agriculture*, 502–503. www.wcca2011.org

UNCTAD. (2013). *Trade and Environment Review 2013: Wake Up Before it is Too Late: Make Agriculture Truly Sustainable Now for Food Security in a Changing Climate*. UN Trade and Development.

UNESCO. (2009). *The United Nations World Water Development Report 3: Water in a Changing World* (Vol. 1). Earthscan.

United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. *General Assembley 70 Session*.

United Republic of Tanzania. (2014). *Review of food and agricultural policies in the United Republic of Tanzania* (MAFAP Country Report Series).

Uphoff, N., Ball, A. S., Fernandes, E., Herren, H., Husson, O., Laing, M., Palm, C., Pretty, J., Sanchez, P., & Sanginga, N. (2006). *Biological approaches to sustainable soil systems*. CRC Press.

Urioste, A. M., Hevia, G. G., Hepper, E. N., Anton, L. E., Bono, A. A., & Buschiazzo, D. E. (2006). Cultivation effects on the distribution of organic carbon, total nitrogen and phosphorus in soils of the semiarid region of Argentinian Pampas. *Geoderma*, *136*(3–4), 621–630.

Valbuena, D., Erenstein, O., Tui, S. H.-K., Abdoulaye, T., Claessens, L., Duncan, A. J., Gérard, B., Rufino, M. C., Teufel, N., & van Rooyen, A. (2012). Conservation Agriculture in mixed crop–livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research*, *132*, 175–184.

Van den Putte, A., Govers, G., Diels, J., Gillijns, K., & Demuzere, M. (2010). Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. *European Journal of Agronomy*, *33*(3), 231–241.

Van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P., & Hochman, Z. (2013). Yield gap analysis with local to global relevance—A review. *Field Crops Research*, *143*, 4–17.

Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B., & Nolte, C. (2014). A fourth principle is required to define conservation agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, *155*, 10–13.

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P., Deckers, J., & Sayre, K. D. (2010). Conservation agriculture, improving soil quality for sustainable production systems. *Advances in Soil Science: Food Security and Soil Quality*, *1799267585*, 137–208.

Vyn, T. J., & Janovicek, K. J. (2001). Potassium placement and tillage system effects on corn response following long-term no till. *Agronomy Journal*, *93*(3), 487–495.

Wall, P. C. (2007). Tailoring conservation agriculture to the needs of small farmers in developing countries: An analysis of issues. *Journal of Crop Improvement*, *19*(1–2), 137–155.

Wall, P. C., Thierfelder, C., Ngwira, A., Govaerts, B., Nyagumbo, I., & Baudron, F. (2013). 11 Conservation Agriculture in Eastern and Southern Africa. In *Conservation agriculture: Global prospects and challenges* (p. 263). CABI, Wallingford Oxfordshire, UK.

Wander, M. M., Walter, G. L., Nissen, T. M., Bollero, G. A., Andrews, S. S., & Cavanaugh-Grant, D. A. (2002). Soil quality. *Agronomy Journal*, *94*(1), 23–32.

Wang, Q., Bai, Y., Gao, H., He, J., Chen, H., Chesney, R. C., Kuhn, N. J., & Li, H. (2008). Soil chemical properties and microbial biomass after 16 years of no-tillage farming on the Loess Plateau, China. *Geoderma*, *144*(3–4), 502–508.

Wardle, D. A. (2002). *Communities and ecosystems: Linking the aboveground and belowground components*. Princeton University Press.

Waring, B. G., Averill, C., & Hawkes, C. V. (2013). Differences in fungal and bacterial physiology alter soil carbon and nitrogen cycling: Insights from meta-analysis and theoretical models. *Ecology Letters*, *16*(7), 887–894.

Watt, M., Silk, W. K., & Passioura, J. B. (2006). Rates of root and organism growth, soil conditions, and temporal and spatial development of the rhizosphere. *Annals of Botany*, *97*(5), 839–855.

Wekesah, F. M., Mutua, E. N., & Izugbara, C. O. (2019). Gender and conservation agriculture in sub-Saharan Africa: A systematic review. *International Journal of Agricultural Sustainability*, *17*(1), 78–91.

West, T. O., & Post, W. M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Science Society of America Journal*, *66*(6), 1930–1946.

Wezel, A., Soboksa, G., McClelland, S., Delespesse, F., & Boissau, A. (2015). The blurred boundaries of ecological, sustainable, and agroecological intensification: A review. *Agronomy for Sustainable Development*, *35*(4), 1283–1295.

Winterbottom, R., Reij, C., Garrity, D., Glover, J., Hellums, D., McGahuey, M., & Scherr, S. (2013). Improving land and water management. *World Resources Institute Working Paper).*, *2*. http.//www.worldresourcesreport.org

World Bank. (2008). *World development report 2008: Agriculture for development*. World Bank.

Yeboah, K., & Jayne, T. S. (2015). *Employment Trends in Sub-Saharan Africa: The Evolving Role of Agriculture. International Development Working Paper.*

Yegon, R., Mtakwa, P. W., Mrema, G. C., & Ngetich, F. K. (2016). Planting Pits' Effects on Soil Nutrients in a Sorghum and Pigeon Pea Rotation in Semi-arid Areas of Eastern Kenya. *Department of Land and Water Management, University of Embu, Kenya*. http://hdl.handle.net/123456789/1280

Yin, X., & Vyn, T. J. (2002). Residual effects of potassium placement and tillage systems for corn on subsequent no-till soybean. *Agronomy Journal*, *94*(5), 1112–1119.

Young Carbon Farmers. (2019). *The importance of carbon in the soil* [Informative]. Future Farmers Network. https://www.futurefarmers.com.au/young-carbon-farmers/carbon-farming/importance-of-carbon-in-the-soil

Young, I. M., & Crawford, J. W. (2004). Interactions and self-organization in the soil-microbe complex. *Science, 304*(5677), 1634–1637.

Zheng, C., Jiang, Y., Chen, C., Sun, Y., Feng, J., Deng, A., Song, Z., & Zhang, W. (2014). The impacts of conservation agriculture on crop yield in China depend on specific practices, crops and cropping regions. *The Crop Journal*, *2*(5), 289–296.

Zibilske, L. M., Bradford, J. M., & Smart, J. R. (2002). Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. *Soil and Tillage Research*, *66*(2), 153–163.

Zobeck, T. M., Halvorson, A. D., Wienhold, B., Acosta-Martinez, V., & Karlen, D. L. (2008). Comparison of two soil quality indexes to evaluate cropping systems in northern Colorado. *Journal of Soil and Water Conservation*, *63*(5), 329–338.

APPENDICES

APPENDIX 1: QUESTIONNAIRE FOR FARMERS AT HOUSEHOLD LEVEL

This Questionnaire will be administered to farmers that participated in SIMLESA project in Morogoro Rural District, Tanzania and Bungoma County, Kenya. SIMLESA project was implemented by CIMMYT through MVIWATA in Morogoro and KARLO in Bungoma.

Focus of this Questionnaire: Factors influencing adoption of Conservation Agriculture

Respondent Number: ___________

District……........................... Ward……………………….... Village……………………

Name of the interviewer……….……………… Date of interview…….......…………

SECTION A: RESPONDENT'S GENERAL INFORMATION

1. Gender: Male ( ) Female ( )
2. How old are you (years)?
3. Marital status: Single ( ) Married ( ) Widowed ( ) Divorced/Separated ( )
4. How many people live in your household? _______
5. What is your highest level of formal education?
   No formal schooling ( ) Standard seven education ( ) "O" Level Secondary ( ) "A" Level secondary education ( ) Vocational training ( ) College ( ) Graduate ( ) Adult education ( ) Other (specify)……………………...
6. Do you have another source of income apart from farming? YES ( ) NO ( )
   Salaried employment ( ) Informal business ( ) Livestock Keeping ( ) Casual labor ( ) Other specify…………………………………………..

SECTION B: INFORMATION ABOUT AGRICULTURE AND LAND TENURE

7. For how long have you been involved in farming activities? ……………...... (Years)
8. How big is the land where you farm? __________________
9. How did you acquire the land? Purchased ( ) Family land ( ) Inherited ( ) Rented ( ) Communal ( ) Other (Specify)…………………………………………
10. What is your source of farm labor?
    Family members ( ) Neighbors ( ) Work group ( ) Hired labor ( )
    Other source (specify)…………………………………………….
11. Where is your farm/plot situated?
    On flat land ( ) On gentle slope ( ) On steep slope ( )
12. What kind of a cropping system do you use on your farm?

Intercropping irrigated farming system ( ) Rain fed intercropping farming system ( )
Mono-cropping irrigated farming system ( ) Rain fed mono-cropping system ( )

13. Do you have an extension agent advising you on recommended practices in Conservation agriculture? YES ( )   NO ( )
14. If YES, how often do you receive advice from this extension agent?
    Once in a month ( )   Once in a production season ( )   Frequently ( )
    Others, specify ……………………...............................……………………………...

SECTION C: RATE OF ADOPTION

15. Did you know about CA before SIMLESA project?   YES ( )   NO ( )

16. What practices did you learn from SIMLESA? (Tick appropriately)

Conservation Agricultural Practices	**Trained**	**Understand**	**Use**
Minimum / zero tillage on farm			
Use of Mulching and Cover crops			
Use of herbicides			
Use of pesticides			
Intercropping maize with legumes			
Retain crop residue after harvesting			
Use of organic manure			
Direct planting of crop seeds on the rip line			
Crop rotations			

17. What is the size of your land under CA?
    ____

18. How much yield do you get from the land under CA (per year/season)?

Crop grown	**Yield before CA**	**Yield after adopting CA**

19. What other changes have you noticed since you started using CA practices?
    a) ____
    b) ____
    c) ____

20. Will you continue using CA?   YES ( )   NO ( )

21. Will you increase the size of land under CA?   YES ( )   NO ( )

22. How many farmers have you trained/learnt from you on CA in your village?
    ____

SECTION D: Attitude towards CA practices among smallholder farmer

23. Indicate by putting a tick on appropriate answers on the corresponding box on the following

Attitude towards Conservation agricultural practices	**I accept**	**Neutral**	**Not accept**
Conservation agriculture improves soil structure, protects the soil from erosion and nutrients losses			
Minimum till operations under CA reduces the amount of labor			
Crop residues on the soil surface enhance water holding capacity			
Mulches protect soil from extreme temperatures and reduce surface evaporation			
Conservation agriculture increases crop yield			
No till agriculture contributes less greenhouse gases into atmosphere and promotes cleaner air			
Agro forestry protects soil from erosion			
Direct planting of crop seeds on the rip line increases yield crop and reduces soil disturbance			
Crop rotations breaks disease cycles on farm			
Manure applied at the appropriate time increases soil fertility			
No burning of crop residues protects soil from sun, rain, wind and to feed soil organisms			
Conservation tillage/reduced tillage protects soil surface			
Cover crops protects soil from moisture and reduces weed growth			

SECTION E: FACTORS THAT INFLUENCE ADOPTION OF CA

24. Considering that in _______________ village _________ farmers were trained/learnt from you on CA and not all of them adopted, why do you think they have not yet adopted? Please indicate your opinion about the following statements by ticking the response that most nearly coincides with your observation.

Statement (Socio-economic and environmental)	**Opinion**		
	Agree	**Uncertain**	**Disagree**

Farmers have low level of education that hinder the adoption of CA			
Income level of most farmers is low for them to adopt CA			
Women farmers are not involved in decision making of adopting CA			
Most farmers around this village have negative attitude towards CA			
Farmers are not aware about the existence of CA			
Farmers do not practice CA because of shortage of labour			
Farmers do not adopt CA because they don't own land			
Most of farmers are old enough and conservatives to adopt CA			
Young farmers have not adopted to CA because they don't have land			
Farmers do not adopt CA because of shortage of land			
CA practices are difficult or technical to implement			
CA Practices are expensive			
It takes a long time to establish CA system on a farm			
This village do not get enough rains to support adoption of CA			

25. Are there any problems/challenges you face in using CA practices? Mention them:

i. …………………………………………………………………………

ii. ………………………………………………………………………….....

iii. …………………………………………………………………………

Thank you