EVALUATION OF THE EFFECTS OF CONSERVATION AGRICULTURE ON SOIL PROPERTIES IN LAIKIPIA COUNTY, KENYA

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DECLARATION

Declaration by the Student

This thesis is my original work and has not been presented for conferment of a degree in any other university or for any other award

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A400/2021P/14.

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Declaration by the Supervisors

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted for examination with our approval as university supervisors

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DEDICATION

I dedicate this work to my beloved family, with special mention to my wife Florence, my daughters; Esther and Precious, my sons; Victor and Titus for their moral support and constant encouragement during my studies. I dedicate my work to my workmates and colleagues for their support and encouragement in various stages of my study. Lastly, but not least, I also dedicate this work to all other friends who committed themselves to stand with me in prayers during the challenging moments of my studies.

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ABBREVIATIONS AND ACRONYMS

ABACO	Africa Agroecology-based aggradation-conservation agriculture
ACT	African Conservation Tillage
AEZs	Agro-Ecological Zones
AGRA	Alliance for a Green Revolution in Africa
ASAL	Arid and Semi-Arid Areas
AU	African Union
BD	Bulk Density
CA	Conservation Agriculture
CA-FFS	Conservation Agriculture Farmers' field school
CEC	Cation Exchange Capacity
CF	Conventional Farming
CIDP	County Integrated Development Plan
CIMMYT	'Centro Internacional de Mejoramiento de Maíz y Trigo International' (Maize and Wheat Improvement Center)
CR	Crop Residue
CSA	Climate Smart Agriculture
DAS	Days after seeding
DGGE	Denaturing Gradient Gel Electrophoresis
DNA	Deoxyribonucleic acid
DW	Distilled Water
FAO	Food and Agriculture Organization
FFS	Farmers' field school
FGD	Focus Group Discussions
FYM	Farm Yard Manure

GTZ	‘Deutsche Gesellschaft für Technische Zusammenarbeit’ (German Agency for Technical Cooperation).
HSD	Honest significance difference
K	Potassium
MBM	Microbial biomass
MoA	Ministry of Agriculture
N	Nitrogen
NARL	National Agricultural Research Laboratories
NGS	Next Generation Sequencing
OUT(s)	Operational Taxonomic Unit(s)
P	Phosphorus
PCR	Polymerized Chain Reaction
PGPB	Plant growth promoting bacteria
PGPR	Plant Growth Promoting Rhizobacteria
RL	Reference Land
RNA	Ribosomal nucleic acid
SCL	Silt clay loam
SOC	Soil Organic Carbon
SOM	Soil Organic matter
SOPs	Standard Operational Procedures
SSA	Sub-Saharan Africa
TIMP(s)	Technologies, Innovations and management practice(s)

ABSTRACT

Conservation agriculture (CA), defined by three principles of; minimum soil disturbance, use of cover crop and crop rotation/diversification was introduced in Laikipia as alternative to conventional farming (CF) systems, to improve soil properties and resilience to climate change and soil degradation. The study investigated practice of CA by farmers and carried out in-situ and laboratory analysis of soil moisture, bulk density, texture, soil nitrogen, phosphorus, exchangeable cations and microbial diversity. The study area was purposively selected to include areas where CA had historically been practised. A population of 2,000 farmers registered as practising CA were interviewed. For the collection of soil samples, 332 farmers were sampled based on; (i) farmers who received training on CA curriculum (ii) farmers who were actively practising all the three principles of CA (minimum soil disturbance, crop rotation and soil cover); and (iii) farmers who were practising CA alongside conventional farming. Thirty (30) farmers were sampled according population in each through proportionate stratified random sampling. 270 composite soil samples were collected from 3x3 m plots at a depth of 0-20 cm (rooting zone) of annual crops, from 30 farms, during 2019 and 2020 cropping seasons. Soil sampling for analysis soil bulk density, moisture) while soil sampling for the analysis of chemical and microbial properties was done using core ring sampler of 5cm diameter and 10cm height and metallic soil augers of 5cm diameter, respectively. The analysis of soil physical and chemical properties were done according to protocols in soil and plant analysis and national agricultural research laboratories (NARL) manuals. The analysis of microbial diversity was done according to functional gene analysis pipeline (www.mrdnalab.com). Findings describing significance differences in soil properties between farming systems were done using one-way analysis of variance (ANOVA) at ($p \leq 0.05$), followed by post-hoc family-wise comparisons of means between experimental plots. Tukey's honest significance difference (HSD) tested mean separation when analysis showed statistically significant differences ($p < 0.05$). The DNA from environmental samples was extracted using PureLink™ Microbiome DNA Purification Kit (Thermo Fisher Scientific). Amplicon generation and sequencing was done using the next generation (NGS) Illumina's MiSeq technology platform (bTEFAP)®. All statistical analyses were performed using IBM SPSS ver 22, R-program and MS-Excel for Windows. Findings of CA farming practices indicated that 67% of farmers employed all the three principles of conservation agriculture (crop cover/residue + crop rotation + no tillage). Majority (62%) of farmers were largely subsistence farmers, growing mainly; maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.). Silt clay loam (SCL) was the most abundant at 60%, while 67.47% of farmers employed all the 3 principles of CA. Farms adopting CA had the highest soil bulk density at 1.78 ±0.04 g/cm3. Soil moisture levels in farms declined significantly from '25" to "75" days after seeding (DAS) under different farming systems. Soil carbon was significantly higher in farms adopting CA, which is postulated to be due to the high use of organic biomass on soil. The study found important rhizospheric bacteria and fungi that affects soil properties. The findings can be used for developing a holistic soil improvement strategy for improving soil properties and enhancing farmer resilience to climate change effects in rain-fed farming systems in Laikipia.

***Key Words**: Climate change, Farming Systems, Productivity, Soil Properties, soil degradation, microbial diversity.*

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Rain-fed agriculture in dry areas which is characterized by low crop yield levels and high on-farm water losses play a critical role in food supply security, as it constitutes up to 80% of the agricultural land worldwide (Sébastien *et al.*, 2019). According to Postma-Blaauw *et al., (*2010) limitations in resources will necessarily put constraints on agricultural production, while the gaps between current farm production and the potential yield are still significant in many farming systems.

The changing rainfall patterns that have changed farming seasons and effected crop production calendars in recent years, has been attributed to climate change (Abadi, 2018). Small holder farmers in semiarid areas, who entirely depended on rain-fed farming, are subject to various hydrological constraints (Sousa *et al.*, 2016; Sebastien *et al*., 2019). In semi-arid areas of Kenya, rainfall occurrence is bimodal with two distinct rainy seasons; the long rains (March to May) and the short rains (October to December), with the latter being more reliable for crop farming (Huho *et al*., 2012). In recent days, a trend of decreasing rainfall and more frequent heavy-rainfall event changes has been observed (Kaumbutho and Kinziele, 2007). Temporal and spatial variability of sporadic and erratic rainfall makes dry land rain-fed farming vulnerable to droughts and floods (Sébastien *et al*., 2019). The impacts of climate change on soil moisture and crop productivity are evident in agricultural production and especially in rain-fed farming systems (Abadi, 2018). In recent studies, soil water deficit and declining soil fertility are among the main challenges facing farming in arid and semi-arid lands (Huho *et al*, 2012). Laikipia is situated on the leeward side of Mount Kenya, which generally creates erratic and low rainfall pattern (400–700mm), leading to inadequate water in rain fed agriculture (Laikipia County Integrated Development Plan (CIDP), 2018-2022). The study area is classified as arid and semi-arid, which is prone to effects of climate change related effects such as frequent drought events, which constraint on crop productivity (Sébastien *et al.*, *2019*; Huho *et al*., 2012).

Intensive farm operations which are widely adopted as the best-best practices to increase food production and food sufficiency have contributed to soil degradation leading to alteration of structure and composition of soil physical, chemical and biological properties (Falkenmark *et al.*, 2019). It is documented that farming operations cause destruction of fundamental structure of the soil composition and damage of soil properties (Araz *et al*., 2014). Postma-Blaauw *et al., (*2010), also noted that agricultural intensification has contributed to adverse effects on soil properties leading to increased soil erosion, oxidation of soil organic matter, disruption of the functions of soil organisms and associated losses of nutrients. Furthermore, farming practices adopted by farmers have exacerbated land degradation (Reynolds *et al*., 2009), affecting soil properties and leading to decline in soil fertility and food production (Das *et al*., 2014). The declining soil fertility has led to poor crop performance in the diverse agro-ecological zones over the years (Ayamba *et al*., 2021). Consequently, current research priorities have focused on restocking soil nutrients mainly using inorganic fertilizer application (AGRA, 2014).

Even with interventions such as the introduction of high yielding improved varieties and the use of inorganic fertilizers to fertilize crops, conventional farming practices have consistently contributed to low productivity (Chartres and Noble, 2015). Godfray and Garnett (2014), proposed the use of genetically modified crops, conventional breeding and crop intensification as the way to achieve increased productivity. Conventional farming systems involving intensive soil tillage and mono-cropping and are largely adopted by majority of farmers in Laikipia, forming about 93% of the farming systems, followed by conservation agriculture (Sousa *et al*., 2016).

Increasing farm productivity by adopting climate smart agriculture (CSA) has gained renewed emphasis from international development agencies since the 2007-2008 food crises (FAO, 2015). The adoption of sustainable farming systems is expected to provide high returns for lower cost of production than in conventional farming. Studies have shown that soils can be replenished owing to a change in farming systems (Tittonell, *et al*., 2012; Edralin *et al*., 2016). However, the major challenges facing many farmers in arid and semi-arid lands (ASAL) is how to improve crop productivity under current conventional farming systems (Sébastien *et al.*, 2019).

Globally, farmers are shifting towards climate smart farming practices as means to manage the effects of climate change on agriculture (Abadi, 2018; Huho and Kosonei, 2013). Researchers and technology developers have over the years been trying to develop appropriate technologies that can be employed to sustain high levels of farm productivity in dry land rain-fed agriculture (Christiansen *et al.*, 2011; Ndah *et al*., 2019). Evidence has shown that soil conservation practices including residue management and reduced tillage, can contribute to soil water retention and soil fertility (Sébastien *et al.*, 2019). With the cost of fertilizer inputs rise and unsustainable supply, governments and proponents of climate smart farming systems are developing climate smart technologies and sustainable farming systems strategies to mitigate climate change effects on sustainable crop production technologies. (Khanal *et al.*, 2021).

Climate smart farming systems are being promoted to reduce the impacts of farming practices on soil structure, improve available soil moisture and reduce soil pliable for farming (Araz *et al*., 2014; Giller *et al*., 2011). Other climate smart strategies include crop productivity improvement strategies, agricultural policies that advocate for the adoption of sustainable climate smart farming systems (McCarthy *et al*., 2011), climate change mitigation strategies that reduce the effects of soil compaction (Huho and Kosonei, 2013); improvement in soil biological activities and carbon storage in the soil (Soussana *et al*., 2010; Farina *et al*., 2011) and improvement in available soil moisture (Araz *et al*., 2014). Several promoters of sustainable farming systems, including FAO, ACTS and GTZ are encouraging farmers to adopt climate-smart technologies, that utilize technology innovations and management practices (TIMPs) as a way to mitigate the effects of climate change (FAO, 2015; Huho and Kosonei, 2013). In addition, farmers are recommended to employ water harvesting technologies, proper weed control, and supply of additional soil nutrients and use of water conservation farming practices (Thierfelder *et al*. 2015; Abadi, 2018)

Conservation agriculture (CA) farming system is one of the farming technologies being promoted as alternative to conventional farming (CF) in dryland farming areas. Conservation agriculture was introduced and promoted in Laikipia to increase crop productivity and resilience to climate change in Laikipia (McCarthy *et al*, 2011; Huho and Kosonei, 2013). FAO, (2015) defines conservation agriculture as farming technology that applies; (i) less soil disturbance; (ii) in-situ retention of crop residue; and (iii) crop rotation or growing of different crops varieties. In other studies, Tittonell *et al*., (2012), defines conservation agriculture as a method of managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment, and has the potential to support crop production under tropical conditions while mitigating natural resource degradation.

Since soil properties are affected gradually during the transition from conventional farming to conservation agriculture, therefore carrying out this study is justified to evaluate the effects of CA. Conservation agriculture was introduced and has been practised as an alternative to conventional farming system in Laikipia for over 15 years, (Kaumbutho and Kienzle, 2007), and is extensively promoted in many parts of Laikipia where heterogeneous farming systems and temporal soil variability exist, most studies on its effects have focused on crop yield performance in farmers' fields (Sousa *et al.,* 2016).

The data obtained in this study will provide information on the categories of farmers, adoption of CA by gender, sex segregation in farming and duration of farming experience, which can be used for individual farmer targeting. Information on farmers' adoption of CA principles will identify capacity gap for possible interventions and capacity development. The study will generate data that show the effects of CA on soil moisture, bulk density, texture, soil nutrient such as nitrogen, phosphorus, potassium and exchangeable (basic) cations and microbial populations owing to their contribution to crop productivity and farmer resilience to climate effects (Abadi, 2018). This study hypothesized that conservation agriculture farming system has significant effects on the selected soil physical, chemical and microbial properties.

1.2 Problem Statement

Laikipia is classified as arid and semi-arid land, which is prone to effects of climate change related effects such as frequent drought events, low and erratic annual rainfall, (Sousa *et al*., 2016; Sebastien *et al*., 2019).

This suggests that, the location of Laikipia on the leeward side of Mount Kenya, generally creates low rainfall pattern (400–700mm), particularly Laikipia East and north sub-counties which formed the largest part of the study area, leading to inadequate soil moisture for rain fed agriculture (Laikipia CIDP, 2018-2022). Subsequently, these events constraint on soil moisture for agricultural activities (Huho *et al.*, 2012; Thierfelder *et al.*, 2014; Falkenmark *et al*., 2019; Sousa *et al.,* (2016).

Farming systems that affect soil aggregation, soil moisture, soil nutrients and soil microbial life, exacerbate further farmers' efforts to improve crop productivity (Packham, 2010; Sébastien *et al.*, 2019; Njeru *et al*., 2013). Evidence how that, conventional farming systems are associated with continuous crop farming has led to soil nutrients mining, accompanied by low rate of nutrient replenishment, non-use of organic amendments and nutrient (Huho *et al*, 2012; LADA, 2011; Packham, 2010). Soil compaction from farming practices, is reported to be as high as 1.6 gcm^{-3}, in some cases which affects crop root development and solute/gaseous movement in the soil (Mutuku, 2015). There is inadequate information on the effects of farming systems on holistic soil properties addressing soil physical, chemical and microbial properties and previous studies have only concentrated on evaluating soil chemical properties and crop yield performance (Gitari *et al*; 2014; Kaumbutho and Kiezle, 2007; Kuria *et al.,* 2011; Jaetzold *et al.,* 2006; Abdullah, 2014).

There is a capacity gap in knowledge of CA practices in the study area. Evidence of poor uptake of CA technology in 2008, where the number of those who had adopted CA dropped from 481 farmers to 346 by 2018 (Kaumbutho and Kienzle, 2007), which is an indication of declining adoption among farmers.

Limited information is documented on the effects of CA farming system on soil properties after many years of CA practices (Mutuku *et al*., 2015; Kuria et al., 2022).

1.3 Justification of the Study

Widespread soil degradation and low yields in East Africa regions (Adadi Berhane, 2018) have prompted investigation on the potential of CA practices to improve soil properties that support long-term productivity (Corbeels *et al.*, 2013).

Promotion and adoption of CA as an alternative to CF system was expected to provide agronomic benefits that enhance soil improvement in the study area, largely affected by climate change and farming practices (Abadi, 2018; Kaumbutho and Kienzle, 2007). Evaluating the effects of CA on the selected soil properties is critical, owing to the important role played by these properties in soil improvement and subsequent contribution to food production in smallholder farm settings. The study findings are expected to provide information on the effects of CA on soil that can be used for decision and design evidence based interventions for improving farming practices for crop productivity, livelihoods and farmer resilience to climate change in the study area and similar conditions (Gitari *et al.,* 2014; Abadi, 2018). The findings are important contribution to science and policy, which is in line with the Malabo Declaration by AU Submit of 2014 and 'COP21' on agro ecology (Mkomwa & Kassam, 2022; Ndah *et al*., 2019; McCarthy *et al*., 2011).

Even after many years of implementation and promotion of CA by county government of Laikipia, evidence has shown declining number of farmers adopting CA consequently, the study is important for capacity and policy development and for designing appropriate farming systems and strategies for holistic soil improvement (AGRA, 2014).

1.4 Research Objectives

1.4.1 Overall Objective

To determine adoption and practices of conservation agriculture (CA) and its effects on selected soil attributes in rain-fed farming areas of Laikipia County, Kenya.

1.4.2 Specific Objectives

i. To evaluate farming practices employed in CA farming system in Laikipia County.

ii. Determination of the effects of CA on soil physical attributes (soil moisture, texture and bulk density in Laikipia County).

iii. Determination of the effects of CA on soil chemical attributes (organic carbon, total nitrogen, phosphorous and exchangeable cations) in Laikipia.

iv. Determination of the effects of CA on diversity of bacteria and fungi in Laikipia.

1.5 Research Hypotheses

$H_1$1: Conservation agriculture farming practices differ significantly among smallholder farmers in rain-fed lowland areas of Laikipia County.

$H_1$2: Conservation agriculture farming practices in rain-fed lowland areas of Laikipia have significant effects on soil water and bulk density.

$H_1$3: Conservation agriculture farming practices in rain-fed lowland areas of Laikipia have significant effects on soil total nitrogen, carbon, available phosphorous and exchangeable cations

$H_1$4: Conservation agriculture farming practices in rain-fed lowland areas of Laikipia have significant effects on soil microbial diversity.

1.6 Scope of the Study

The study evaluated adoption of farming practices in conservation agriculture (CA) in rain-fed farming areas of Laikipia County in Kenya and determined the effects of farming practices on selected soil attributes in the top soil for their role in productivity. On farming practices, the study was limited two farming systems specifically the conservation agriculture and conventional farming (CF) systems. A section of the land that had not been cultivated for at least three years was also evaluated. On soil physical properties, the study was limited to evaluating the effects of CA on; soil moisture, soil texture and soil bulk density. On soil chemical properties, the study was limited to determining the effects of CA on soil organic carbon, total nitrogen, phosphorous and exchangeable cations, while on soil microbial properties, the study was limited to determining the effects of CA on diversity of soil bacteria and fungi.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction to Farming Systems.

The important anthropogenic activities that influence soil physical, chemical and biological conditions in farming systems include; soil tillage, fertilization plans, weed control methods, farming tools and implements, crop residue (CR), retention and crop rotation (Gol, 2009; Seitzinger *et al*., 2010). Packham, (2010) defines farming systems as collection of principles applied in farm production processes whose aim is to improve agricultural performance. The principal farming practices employed by farmers in both small subsistence units and large corporations can have significant effects on soil properties (Abadi, 2018).

According to Baudron, *et al*., (2013) new farming technologies do not necessarily respond to common biophysical and socio-economic constraints of smallholders. Ndah *et al*., (2019) showed that farmers' perceived low feasibility in combination with uncertainty regarding the relevance and benefits of these practices which is an important constraint towards adoption of conservation agriculture practices. Farmers are firmly convinced that burning CR is necessary for controlling pests and for improving soil fertility and it would require an important paradigm shift in farmer's mindset to change that in favor of longer-term and higher-level benefits such as carbon sequestration (Valbuena *et al.*, 2012; Ndah *et al*., 2019).

There is an increased awareness among scholars that the relevance of conservation agriculture farming practices, and is depended on the local conditions and constraints which can limit the expected benefits of CA (Giller *et al*., 2011).

Although we cannot make generalized conclusions concerning pedo-climatic conditions, some studies have indicated the conditions under which CA would likely not result in benefits compared to conventional practices (Tittonell, *et al*., 2012; Farooq *et al*., 2011; Araz, 2014). The role of farming systems in the maintenance of long-term soil fertility of agricultural soils cannot be underestimated since each farming system employ farming practices that affect soil parameters and nutrient recycling differently (Packham, 2010; Giller, *et al*; 2011).

The adoption of different farming systems by farmers are said to influence not only soil chemical fertility but also a wide range of important physical and microbial attributes that influence crop productivity (Ndah *et al*., 2019). Studies done in the drier zones where soil moisture is limited and soil erosion is prevalent, have mainly evaluated the effects of farming practices on crop yield performance (AGRA, 2014), with limited work on the effects of farming to the soil properties. With evidence that degradation of the land from farming practices has resulted to decline in soil fertility (LADA, 2011), most farmers are continuously practicing intensive land tillage and use of high inputs to achieve higher crop produce, without employing soil and water conservation strategies (Falkenmark *et al*., 2019). Studies by Wang *et al*., (2017), demonstrated that retention and decomposition of crop residues in farming systems facilitated infiltration and increased retention of water into soil. Improvement of soil quality has been observed following long-term residue retention and legume cultivation in maize-based no-till systems in semi-arid areas (Kuria *et al*., 2022).

Crop residue retention and use of cover crops have been reported to affect soil microbial biomass (MBM), total nitrogen and extractable phosphorus, total soil organic carbon levels, as well as the biological activity of soil beneficial and detrimental microfauna (Wani and Khan, 2010).

In crop residue management, a combination of CR retention and soil tillage seemed to be the most popular practice adopted by farmers adopting CA, as they have been shown to provide greater soil improvement benefits as compared to those of CR mulching with minimum soil disturbance (Ndah *et al*., 2019).

Farming practices can increase infiltration and soil water use efficiency and reduce soil and water losses in agricultural production processes. Farming practices that employ mulching of the soils with CR contributed to a large extent to increases in soil water storage. Studies in sub-Saharan Africa showed that CA can contribute significantly to soil carbon sequestration per unit of grain produced when compared to other farming practices (Corbeels *et al*., 2019).

Soil quality has been observed to improve following residue retention and legume cultivation in maize-based no-till systems in semi-arid and sub-humid environments, but such improvement is usually a long-term process (Ngetich *et al*., 2014; Thierfelder *et al.*, 2014). The CR management seems to be the most important practice because when CR is incorporated with tillage, the soil improvement benefits are greater than mulching with minimum soil disturbance (Guto *et al*., 2011). Farming practices that retain substantial organic biomass on soil have been associated with increased water infiltration and water use efficiency and decrease soil and water losses in agricultural production processes (Kuria *et al*., 2022).

Farming approaches that can increase soil fertility and food production should essentially be supported by data driven evidence through appropriate field research. Simultaneous evaluation of the long-term effects of conventional farming (CF) *versus* conservation agriculture (CA) on soils in the study area under farmers' practice is strikingly limited. Most studies on soil fertility in the study area have been confined to a single one time testing of soil chemical elements in farms.

This study assessed the effect of long-term (>15 yrs) adoption and practice of CA on soil physical, chemical, and microbial properties in farmers' fields amidst technical and natural occurrences.

2.2 Climatic and Partitioning of Rainfall Water.

According to Thierfelder *et al*., (2014), crop production in Kenya and in sub-Saharan Africa is majorly rain-fed. However, low and erratic rainfall patterns characterized by frequent droughts and prolonged dry spells lead to crop failure (Huho *et al*., 2012). Low and erratic rainfall lead to deficit in soil moisture and crop stress that result to crop failure associated with low crop productivity and increased food insecurity in ASAL areas (Abadi, 2018). In spite of arid and semi-arid areas receiving average rainfall of between 400-1000 mm annually, there is no doubt that water is a major constraint towards agricultural productivity in these areas.

Rainfall patterns in ASAL regions are characterized by erratic, high intensity rainfall with recurrent droughts and dry spells. The arid and semi-arid areas are within the most water scarce regions and are expected to face water shortage over the next generation (Abadi, 2018). Prolonged period of rainfall below normal followed by extended dry seasons results in a significant reduction in cumulative seasonal rain water (Huho *et al*., 2012). This situation is further exacerbated by farming systems that use intensive soil tillage and less of soil water conservation technologies. Rainfall in the study area is highly erratic and, in some cases, heavy, often with very extreme spatial and temporal variability. There is also high probability for annual droughts occurrence resulting to total crop failure in most cases (Falkenmark *et al*., 2019). According to Sébastien *et al*., (2019), most farmers in the arid and semi-arid land (ASAL), rely on rain fed farming.

The length of crop growing period (CGP) for the short season maize and beans in the study area ranges from 75-120 days in ASAL areas, which is determined by the relationship between rainfall and the potential evapotranspiration (PET). This means that the cumulative PET for the growing season is less than 400 mm, which explains why soil water in these areas is inadequate to sustain a full cycle of crop to growth (Abadi, 2018). Low erratic rainfall, followed by high marginal temperatures and dry spell periods can lead to water stress in crops. Periods of water stress in dry land farming if occurring during water sensitive development stages such as during; germination, flowering or grain filling stages, can have a serious effect on crop yield performance (Kenya seed, 2010). This implies that low and poorly distributed rainfall over time and high marginal temperatures in ASAL areas often constitute a more common cause for crop failure due to low cumulative soil moisture; than absolute water scarcity leading to 'agricultural drought' (AD). According to Falkenmark *et al*., (2001), 'agricultural drought' occurs when the cumulative plant available soil water is significantly lower than cumulative crop water requirements. Agricultural droughts can be man-made, for example due to poor land management practices that result to high soil bulk density levels leading to low infiltration, low water holding capacity and poor plant water uptake capacity. When it rains soil and water erosion and compacted soils with high bulk density makes water infiltration and availability to crops very difficult (Baudron *et al*., 2013). According to Falkenmark *et al.*, (2019), nature has the ability to partition rainfall water in such a way, that it can be utilized in food production.

According to Falkenmark, *et al.*, (2019), rainfall partitioning concept, assumes that rainfall water received when it rains constitute 100% of soil moisture (figure 1). He further demonstrated that soil water evaporation in semi-arid regions accounts for 30-50 % of rainfall and can exceed 50 % in crops that have been sparsely spaced. According to this model, 15-30% of rain water is lost through plant transpiration (evapotranspiration), 10-25% through surface run-off and 10-30% by ground percolation. The increased rate of soil water evaporation from the top profile due to exposure to the atmosphere reduces soil moisture available to crops. This is due to the agro-meteorological conditions under which crop production generally occurs under rain-fed farming systems with high net air temperatures and significant wind, resulting in high turbulence.

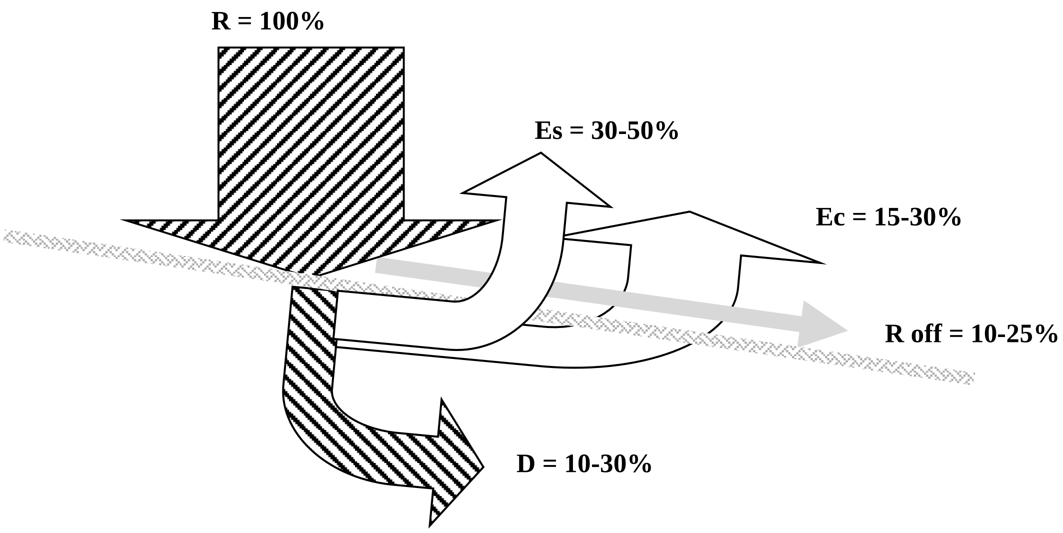

Figure 1. A theoretical overview of rainfall partitioning in farming systems in the semi-arid tropics. R = Rainfall, Ec =Plant transpiration, Es = Evaporation from soil and through interception, Roff = Surface runoff, D = Deep percolation. (Adopted with modification from; Falkenmark et al., 2019).

The result is that, water flow as transpiration in general account for merely 15-30% of rainfall. The rest, between 70-85 % of rainfall, is "lost" from the cropping system as non-productive green water flow (as soil evaporation) and as blue water flow (deep percolation and surface runoff).

Therefore, since majority of farmers in ASALs areas depend on rainfall as their main source of water for farming purpose and rarely on irrigation (i.e. blue water) farming production has always depended on the annual cumulative rainfall (i.e. green water) (Sebastien *et al*., 2019). It is noted that, soil management practices through farming systems can also contribute to poor rainfall partitioning resulting in soil water scarcity in the root zone causing an 'agricultural drought' (Falkenmark *et al*., 2019).

The current study area falls under arid and semi-arid areas and experiences prolonged periods of abnormally low rainfall resulting in complete crop failure during crop growing seasons (Falkenmark *et al*., 2019). However, the amount of rainfall received alone is not the only limiting factor in crop production, but its distribution and reliability is an important factor in semi-arid farming (Sousa *et al*., 2016). Much of the study area lies to the lee side of Mount Kenya, and the area is characterized by erratic and low rainfall with surface runoff leading to moisture stress to crops (Sébastien *et al*., 2019). According to Kaumbutho and Kienzle (2007), degradation of soil physical properties from farming practices exacerbates already existing soil moisture constraints as efficient soil moisture use by crops depends on the condition of soil physical properties. There is a high risk of soil water scarcity in crop production resulting from induced human practices, irrespective of spatial and temporal rainfall variability. Farming practices that ensure timely planting, water harvesting and efficient use of rain water through appropriate land management technologies in dry land farming systems are required (Kuria *et al.*, 2022).

2.3 Role of Farming Systems in Improving Soil Productivity

Increase in the growth of world population is expected to impact on food production requirements (FAO, 2015). Increasing food production to feed the growing population depends not only on rainfall but also on the use of climate smart farming technologies that are sustainable and that reduce pressure on farm land.

Food production in semi-arid areas that are considered to host 7% of the world’s population has been impacted by climate change and variability (Falkenmark *et al*., 2019; Huho and Kosonei, 2013). Persistent food insecurity accompanied by low and declining soil fertility in rain-fed agriculture is attributed to low and declining agricultural production and productivity (Thierfelder *et al*., 2014) in the current farming systems. Dependency of rain water in rain fed agriculture according to (Kenya Seed Co, 2010) has always been used as an arguments to rule out the potential of these areas as grain baskets. Contrary to this believe, evidence has shown that adoption of climate smart farming systems that conserve soil moisture and improve soil organic matter can be a solution to reduce high water deficits and high soil bulk densities that impede crop production in these areas (Ndah *et al*., 2019; Christiansen *et al.,* 2011).

The gap between research and application of findings on farming systems is wide and there is low uptake and utilization of recommendations on farming technologies by smallholder farmers. Lack of harmonized approach and conflicting recommendations to the end users by different promoters of climate smart agriculture technologies and innovations is one of the reason for low technology adoption (Christiansen *et al.,* 2011; Njeru *et al*., 2013).

Researchers and promoters of sustainable farming systems are advocating for farming systems that can conserve soil moisture and improve plant available soil water (Falkenmark *et al.,* 2019), reduce soil compaction and facilitate free root penetration (Sebastienet *et al*., 2019; Erenstein *et al*., 2012), store carbon in the soil (Farina *et al*., 2011) and improve plant available soil nutrients (Araz *et al*., 2014).

The use of minimum tillage as a way of reducing soil disturbance and improving soil moisture storage is an important principle in farming systems (Kaumbutho and Kienzle, 2007). Recent research by Falkenmark *et al*., (2001), suggests that with adoption and proper practice of climate smart farming systems, the prospect of doubling or even quadrupling yields is realistic even within the context of high risk for meteorological droughts. Findings from previous studies have demonstrated that adoption of climate smart agriculture farming systems can indeed increase resilience to climate stress (Christiansen *et al.*, 2011). However, it has been found that the benefits arising from conservation agriculture can only be realized after at least three years period of full CA practice (Kuria *et al.*, 2022). Currently, the effect of CA farming system in increasing maize performance by up to 80% has been demonstrated in a series of on farm and controlled experiments in agricultural research stations (Thierfelder *et al.*, 2014; Guto *et al*., 2011).

2.4. Introduction and Adoption of Conservation Agriculture Farming Technology.

Conventional farming systems are defined by use of heavy machinery in soil tillage during land preparation, followed by gathering and burning or feeding of CR to livestock (Valbuena *et al*., 2012).

On the other hand, FAO (2019) defines conservation agriculture as a farming technology that applies three linked principles of; (i) minimum mechanical soil disturbance; (ii) continuous permanent organic soil cover and crop rotation and/or (iii) diversification of crop species grown in sequences and/or associations. Conservation agriculture (CA) farming system was introduced by farmers and scientists in Brazil in the early 1970s, and is currently adopted on nearly 10% of the total cropland in the world (Friedrich *et al*., 2012).

Its practice in the USA started in the 1960s (Sebastien *et al*., 2019; Lindwall, 2010) and fast adoption rates are currently being experienced in Central Asia, alongside increasing policy support and early large-scale adoption taking place in Zambia, Zimbabwe, South Africa, Tanzania, Kenya, Morocco, and Tunisia. Europe has some few pockets of adoption, particularly in Finland, Spain, France, Italy, the United Kingdom and Switzerland (Friedrich *et al*., 2012). In Africa, conservation agriculture is promoted as an alternative for coping with the need to increase food production on the basis of more sustainable farming practices (Thierfelder *et al.*, 2014; Murungu, 2012). In Kenya, evidence of CA is documented in the larger Nzoia River Basin covering Kitale, Bungoma, Vihiga, Bunyore and in central and rift valley region covering Limuru and Laikipia (Kaumbutho & Kienzle, 2007).

Dissemination of conservation agriculture farming technologies, like any other technology requires understanding of adoption cycle described by Friedrich *et al*., (2012), as illustrated in Figure 2.

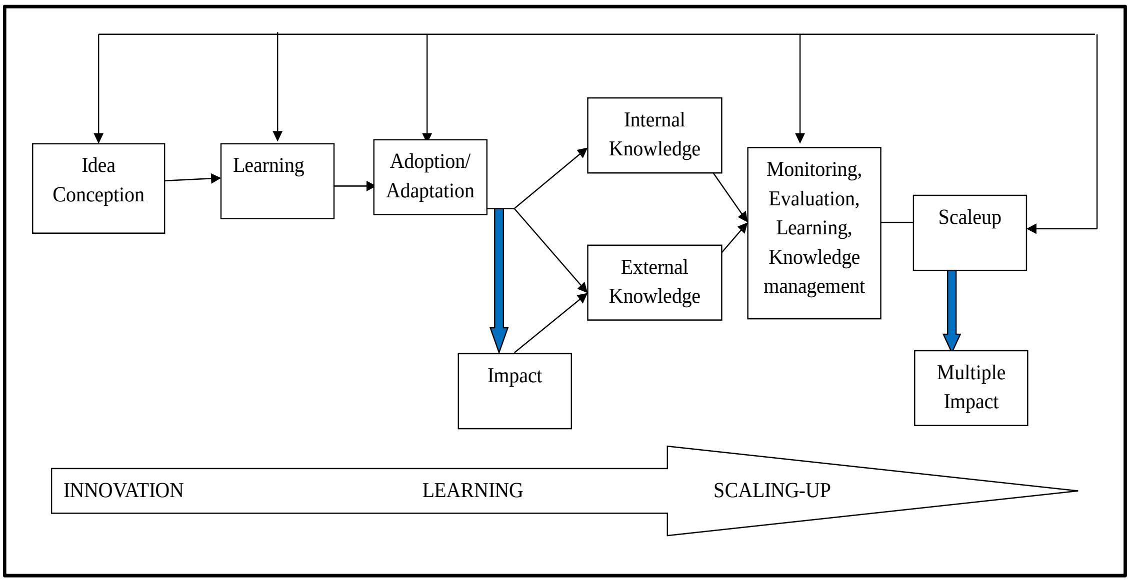

Figure 2. A Theoretical framework on pathways to scale technology adoption and adaptation (Adopted and modified from Linn, 2011; Christiansen et al., 2011).

McCarthy *et al*., (2011), argues that adoption of farming technology must reveal farmers' inputs and situations that underpin its adoption or non-adoption of the technology being promoted. Scholars and promoters of CA favor more practical and context-specific approaches over the strict implementation of CA principles (Thierfelder *et al.,* 2014; Ndah *et al.,* 2019). The question as to whether CA principles are applicable in the context of smallholder farming practices, whose resources are limited is debatable (Guto *et al*., 2011). Adoption and adaption of CA principles by farmers have been shown to provide significant benefits on soil properties and crop productivity (FAO, 2019; Erenstein *et al*., 2012).

2.4 Promotion of Conservation Agriculture Farming System in Laikipia

Several farming systems are adopted by farmers in Laikipia County, the two major ones remain; conventional farming (CF) system and conservation agriculture (CA) (Kaumbutho and Kienzle, 2007). Conservation agriculture was initially introduced in Laikipia East and North sub-counties in 1990s, as an alternative to conventional farming system largely practised by majority of farmers in the study area (Kaumbutho and Kienzle, (2007). From 1997 to 2008, the government through the ministry of agriculture partnered with agro-ecology based aggradation conservation agriculture (ABACO, 2012), the African conservation tillage (ACT), Food and agriculture organization (FAO) and African green revolution in agriculture (AGRA, 2014). Between 2009 and 2010, FAO and Kenya Agricultural Research Institute (KARI) promoted adoption of CA in Laikipia and later in 2011 to 2013, European Union (EU) and African Conservation Tillage (ACT). These concerted efforts gave rise to the formation of eight (8) farmer field schools (FFS) who received training on principles of CA and later applied their skills on their farms with support of the government and stakeholders.

The stakeholders who participated in the promotion of CA in the study area included; African conservation tillage (ACT) and Alliance for green revolution in Africa (AGRA, 2014) (Kaumbutho and Kienzle, 2007). Champion farmers and field extension staff from department of agriculture in collaboration with staff from the funding agencies and collaborators spread the knowledge on CA among farmers through advisory services. The period from 2004-2010, was characterized by intensive CA training to farmers' field schools (FFS) based in selected wards and the field extension staff from the county department of agriculture (Kaumbutho and Kienzle, 2007; Kuria *et al*., 2022).

Conservation agriculture was introduced in the study area for its perceived benefits in improving soil and crop productivity amid climate change, and has since been practised alongside conventional farming systems (Kaumbutho and Kienzle, 2007). The use of crop rotation, minimum soil disturbance and soil organic mulch in CA farming systems has been associated with the improvement of soil moisture, suppression of weeds, nutrient cycling for optimum crop production (Wang *et al.,* 2019). Where CA is practiced in the study area, common leguminous crops are grown as inter-crops with main cereal crops in order to serve as cover crops until maturity when they are harvested for food (Kaumbutho and Kienzle, 2007). Beans (*Phaseolus vulgaris* L.), Mucuna (*Pucuna pruriens*) and black beans (*Lablab purpureus* (L.) are the most commonly used cover crops intercropped with maize to provide residue cover in CA farming (FAO, 2019; Giller *et al*., 2011).

In analyzing the actual farm benefits of CA, it is important to understand the gradual effects of CA on agricultural soils, since these effects directly influence the physical, chemical and biological soil properties associated with soil fertility and hence crop productivity (FAO, 2015).

Even though there is a lot of interest in CA, Reynolds *et al*., (2009), argued that the effects CA as a proof of its benefits is limited and inconsistent in semi-arid farming has been reported (Thierfelder *et al*., 2014). Previous attempts to evaluate the impact of CA on soil fertility in Laikipia by African Conservation Tillage, involving on-farm comparative studies on yield performance of maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) under CA and CF farming systems, were done between 2010 and 2012 (AGRA, 2014; Kaumbutho and Kienzle, (2007). Literature has provided limited studies on the effect of CA adoption on soil properties, (Ahuja *et al*., 2006).

According to Giller *et al*., (2011), the effects of CA are agro-ecology specific and its effects on soil properties may exhibit temporal and spatial variability, this implies that its effects and that of other farming systems may differ significantly in one region from the other (Ndah *et al*., 2019). Previous studies on conservation agriculture and conventional farming systems on yield, indicated that crop yields are generally higher under conservation farming in rain-fed crop production systems in rain-fed lowland areas, especially when all the three principles of CA; i.e. minimum tillage, crop rotation and use of crop residue for mulch are combined (FAO, 2019; Teame *et al*., 2017; Kassam *et al.* 2009). A large-scale assessment from four countries in southern Africa shows yield increases by CA in 80% of the cases, compared to conventional practices (Thierfelder *et al*., 2014).

2.5 Effect of Farming Systems on Soil Properties

Soil health can be inferred from soil properties and soil behavior resulting from the fact that it corresponds to dynamic soil qualities associated with change in land use management practices, inherent and dynamic soil properties (Bainard *et al.,* 2017; Gol, 2009).

Soil texture, soil bulk density and soil moisture are among the major soil physical properties that are critically affected by soil degradation (Kaufmann *et al*., 2010). Soil texture is defined by the USDA soil classification systems as the relative proportion of various particles of sand, clay and silt (USDA, 2017). The relative sizes of various soil particles of sand, clay and silt according to USDA soil classification, are presented as; gravel and pebbles > 2.0 mm, coarse sand: 0.2 -2.0 mm, fine sand:0.02– 0.2 mm, silt: 0.002– 0.02 mm and clay: < 0.002 mm diameter (ASTM D7928-21e, 2021).

Soil bulk density (BD) or compactness referred to as the weight (mass) of soil per unit volume, and is an index of porosity and compaction is expressed as weight (g) divided by volume (gcm^{-3}) (Kaufmann *et al*., 2010). Soil bulk density is a major factor that is affected following a change in farming system. Soil management practices cause soil compaction which may increase bulk density and reduce the mobility of nutrients in the soil, thus contributing to decline in soil nutrients and decrease in crop yield performance (Kaufmann *et al*., 2010). Bulk density affects crop root development and solute/gaseous movement (University of Plymouth, 2006). The effect of tillage and crop residue employed in some farming systems is progressive and initial years of change from one farming system to another might result to small changes and sometimes no differences in bulk density under different farming systems (Gomez *et al.*, 2009; Verhulst, 2010). An-eight year study by Kaufman *et al.*, (2010), showed that the mean soil bulk density is lower in some farming practices than in others and will range between 0.9-1.8 depending on the soil type. According to Reynolds *et al*., (2009), the optimum bulk density values for crop land in fine textured soils ranges between 0.9 and 1.4 gcm^{-3}, 1.4-1.6 gcm^{-3} for mild textured soils and 1.6-1.8 gcm^{-3} for course textured soils.

Evidence show that, BD values below 0.9 gcm^{-3} may result in insufficient contact between soil and roots, poor water retention and plant anchoring, while bulk density values above 1.8 gcm^{-3} may prevent root growth or reduce soil aeration (Reynolds *et al*., 2009). The critical value of soil bulk density for hindering root penetration will vary depending on soil type found in different farms (Hunt and Gikes, 1992), but generally, bulk density must be greater than 1.6 gcm^{-3} to restrict root penetration (Mckenzie *et al*, 2004).

According to Manyatsi *et al*., (2011), bulk density affects infiltration, rooting depth, moisture, soil porosity, aeration and mobility of plant nutrients, all of which influence key soil processes and productivity. Soil bulk density and total porosity are inversely related such that increase of bulk density leads to decrease in total soil porosity (Verhulst, 2010; Govaert et al; 2007). Studies by Kaufman *et al*., 2010), revealed that the changes in mean soil bulk density resulting from different farming practices was between 0.8-1.5 percent.

Tillage practices change the arrangement of soil pores reducing their ability to transport water (Cornelis *et al*., 2013). Measurement of soil moisture is necessary for determination of total field water holding capacity, capillary moisture content and wilting point (Abadi *et al*., 2018). Wang *et al*., 2017), showed that farming practices had effects on soil water and that the yield gain or loss in rain-fed food production systems is dependent on water availability (Gomez *et al*., 2009). In Laikipia County, a large proportion of the arable land is located in water scarce areas where recurrent dry spells and periods of drought occur every rainfall season leading to major yield reduction due to water stress during crop growth. Consequently, high soil moisture deficits experienced in farming soils, leads to significant decreases in crop yields under rain-fed conditions (Sébastien *et al*., 2019).

In other studies, soil moisture deficit in rain-fed farming is attributed to low infiltration rates caused by soil compaction and crusting with high rates of surface runoff during heavy rains (Kaufman *et al.,* 2010).

Farmers need to adopt appropriate farming technologies that not only aid in improving soil rainwater partitioning and conservation of soil moisture, but also one that can manage soil bulk density and conserve adequate soil moisture to enable crop growth to full maturity stage (Kenya seed. Co, 2010).

2.6 Soil Chemical Properties

The amount of mineral nutrients available in the soils according to Gomez *et al*., (2009), is greatly determined by fertilization programs and land management practices. Plant essential elements needed by crops for growth and maintenance are classified according to quantities required. Those required in large quantities, (macro-nutrients) include; N, K, Cal, Mg, P, and S while those required in small quantities (micro-nutrients) include; S, Cl, Fe, B, Mn, Zn, Cu, Mo, and Ni (Wawrzyńska and Sirko, 2014). Among the macro-elements studied included; nitrogen (N), phosphorous (P) potassium (K), magnesium (Mg) and calcium (Cal) and organic carbon (C) (Govaerts *et al.,* 2007; Wawrzyńska and Sirko, 2014).

In farming practices, inorganic fertilizers are ideally applied to supplement soil nutrients lost either through soil erosion or by being mined through crop production. The main aim of fertilizer application is to achieve optimum production, where applications at each location are adjusted according to the estimated crop requirements, based on spatial variability of macro-nutrients within individual agricultural fields.

In most cases, essential macro-nutrients required by crops for the growth and yield must be supplied through soil inputs, while in some other cases, the micro-nutrients are usually found in sufficient amounts in the soil (Wawrzyńska and Sirko, 2014; Cooper *et al*., 2014). The current soil testing practices by farmers involving mainly soil chemical analysis, does not provide adequate information for making a holistic soil fertility decisions due to lack of background information on soil physical and biological parameters, such as soil bulk density, soils moisture and microbial populations (Gitari *et al*., 2014; Wawrzyńska and Sirko, (2014).

2.6.1 Soil pH

Soil pH is the negative log of hydrogen ions (H^+) concentration that describes the relative acidity or basicity of a soil. When the concentration of hydrogen ions (H^+) in the soil colloids is higher than that of hydroxyl (OH^-), the soil is said to be acidic, but when the hydroxyl (OH^-) present in the soil colloids are more than the hydrogen ions (H^+), the soils are said to be alkaline (Govaerts *et al.,* 2007). As described by Keeler *et al*., (2009), soils having a pH of from 5.0 to 6.5, are considered as slightly acidic, and those with pH below 4.0, are considered to be very acidic.

A soil pH range of between 6.5 (slightly acidic) to 7.5 (slightly alkaline) is generally considered to be optimal for availability of most nutrients in the soil (Crop Nutrition, 2016). Plant nutrients like Potassium (K) and Nitrogen (N) are rarely affected directly by soil pH, however, at pH values greater than 7.5, soil phosphorus (P) is affected. When the soil pH is greater than 7.5, most of the micro-nutrients available in the soil tends to decrease, when soil pH is lower than 4.0, micro-nutrients such as zinc and aluminum are said to be in high levels, and can lead to metal toxicity (Brady and Weil, 2002).

In the same way, soils with a pH value of from 7.5 to 8.0 are considered to be slightly alkaline while those with a pH above 8.0 are considered to be very alkaline (Table 1).

Table 1. Soil pH Recommended Level based on soil Texture.

Level	Peat	Loam	Sand
Very Low (acid)	4.0	5.0	5.0
Low	4.5-5.0	5.1-5.5	5.1-5.8
Medium	5.1-5.5	5.6-6.5	5.9-6.8
High	5.6-6.0	6.6-7.0	6.9-7.5
Very high (Alkaline)	>6.0	>7.0	>7.5

Adopted, from Mangale *et al.*, (2016). Field and Laboratory Research Manual for Integrated Soil Fertility Management in Kenya.

At high pH, elements such as magnesium and calcium tend to be abundant in the soil solution. Field reports have shown that, for most of the smallholder farms, soil acidification is a concern, as acidity is created by removal of cationic bases (Ca^+, Mg^+, K^+, and Na^+); harvested crops; leaching, and an acid residual left in the soil from N fertilizers. If surface soil pH is too high or too low, the efficacy of some herbicides and other chemical reactions may be affected.

2.6.2 Soil Total Nitrogen

According to Porter *et al*., (2014), Nitrogen (N) remains one of most important among the essential nutrients in crop production and can be obtained from different sources which include agricultural inorganic fertilizers, atmospheric N fixation and groundwater input. Farming systems employed by farmers, can reduce nitrogen losses by immobilizing and accumulating it to the top soil layer. Farming practices employed by farmers are associated with high net nitrogen mineralization and nitrification rates and release of greater quantities of ammonium (NH_4^+) (Bhattacharyya and Jha, 2012).

Total nitrogen in soils is referred to mean levels of available N of both inorganic and organic inputs in soil shift resulting from decomposition, mineralization and immobilization (Shibu *et al.,* 2010). The measure and choice of crop residues used in CA determines the N availability (Gentile *et al*., 2011). The transition from conventional agriculture to conservation agriculture (CA) is often can lead to decreased in soil nitrogen (N), especially in the first five years (Sommer *et al*., 2014) . The soil available N for crop uptake is sometimes immobilized or mineralized by microbial action on organic residues and especially during the early years of transition from CA to CF. In the event of N immobilization, this contributes to decline in crop yields, and therefore, researchers and promoters of CA have recommended the inclusion of N management during the initial stages of conversation for CA to CF farming (Sommer *et al*., 2014; Kong *et al*., 2009).

2.6.3 Total Soil Organic Carbon (SOC)

According to Wang *et al*., (2013), soil organic carbon indirectly influences soil chemical properties. Although several studies have been carried out on the effects of farming systems on soil organic carbon in different soil types and regions (Thierfelder *et al*., 2014), most of the finding show varying results on the levels of soil carbon stocks. Generally, findings in most of the studies show that farming systems that employ regenerative practices are likely to have higher levels of SOC, than those that employ heavy soil tillage practices (Kadiri *et al.,* (2021). Studies have also established that there is enough evidence of marked increase in SOC in conservation farming systems and fallow, grassland or forested lands where farming activities or falling foliage tend to in-cooperate more biomass retention in the soil and is consistent with the findings by Rahman *et a*l., (2020).

According to Rahman *et al.*, (2020), soils in croplands are characterized by accelerated weathering and SOC oxidation due to farming activities therefore reducing organic matter inputs to the soil and affecting the SOC stock levels. This could be attributed to the continuous biomass turnover from crop residue favoring carbon accumulation (Degu *et al*., 2019). Another factor associated with decreasing trends in SOC stock in conventional farming systems is the fact that there is reduced retention of crop residues on soils and the use of crop biomass as feed for livestock, which is consistent with studies carried out in Tanzania by Alavaisha *et al.*, (2019).

2.6.4 Soil Exchangeable Cations

According to Brady and Weil, (2002), retention and release of soil basic cations; calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}) is dependent on the buffering capacity of the soils and farming systems. The balancing of exchangeable cations movement in the soil is affected by tillage activities that loosen soils and make the movement of cations to the lower levels (Wang *et al*., 2013). Kwiatkowski *et al.*, (2020), however reported that Ca^{2+}, Mg^{2+} and sodium (Na^{+}) are less affected by farming practices.

2.6.5 Soil Phosphorous

Soil phosphorus (P) is the second most important plant nutrient after soil nitrogen, and is abundantly available in soils, both in organic and inorganic forms (Zhang *et al*., 2019). The amount of available P in the soil that crops can readily absorb is in form of monobasic ($H_2PO_4^-$) and the dibasic (HPO_4^{2-}) ions, while the rest is found in insoluble forms (Govaerts, *et al.*, 2007). In the traditional low inputs lowland farming systems, phosphorus deficiency is among the main biophysical constraints to food production caused by inherently low levels of P in the soil exacerbated by high P fixation in acidic soils and loss through water erosion (Kwiatkowski *et al*., 2020).

Leguminous crops used as cover crops in farming systems contribute to a more favorable chemical, physical and microbial composition of soils, (Harasim *et al*., 2020).

Despite its promotion and adoption in areas with phosphorus (P) deficient soils such as western Kenya, CA has not been explicitly considered for its potential to improve soil P availability. Phosphorus remains a major limitation to agricultural productivity in western Kenya (Mutuku *et al*., 2015). This has also been confirmed in field soil analysis carried on farms in Laikipia (Laikipia county agriculture office report (2013).

2.7 Soil Microbial Properties

Bacteria and fungi are the most important micro-organisms in soil that aid in most of the soil formation activities (Wani and Khan, 2010). Balota *et al*., (2003), proposes that the role of microorganisms in releasing nutrients and maintaining soil structure, contribution to moisture storage and transfer in soils and carbon sequestration cannot be overemphasized. According to (Wani and Khan, 2010), different bacterial genera stimulate plant growth by mobilizing nutrients in the soils and produce numerous plant growth regulators.

2.7.1 Effect of Farming Systems on Soil Microbial Diversity

Soil microorganisms are sensitivity to soil management practices and this makes them important early indicators of soil health (Njira and Nabwami, 2013). Accumulated soil microbial diversity and activities are bucked up by organic biomass that also provide carbon for microorganisms (Quio *et al.*, 2012). Farming systems that recycle back crop residues to the field after crop harvest significantly increase the activity of a widerange of soil micro activity, due to the stimulation of enzymes (Zhang *et al*., 2015). Activation of microbes in the root zone and the improved soil physical condition in crop rotations have been ascertained, especially when leguminous crops have been established in a farming system.

Interactive peer between soil microbes and plant roots (rhizosphere) are expedited through the release of root exudates, resulting to reinforced nutrient cycling, plant growth promotion, and disease resistance (Quio *et al.*, 2012), resulting in enhanced soil fertility and crop productivity.

It has been reported that amassed soil microbial diversity will increase the ability of a well-functioning ecosystem or a more efficiently under a different environmental conditions (Quio *et al.*, 2012), implying greater resilience (Seneviratne *et al*., 2011).

The rhizobacteria which are more versatile in transforming, mobilizing and solubilizing soil nutrients, are equally sensitive to human activities on soil (Hayat *et al*., 2010). Symbiotic mycorrhizal fungi, such as arbuscular mycorrhizal (AM) fungi that form a key component of the microbial populations in farmed soils, are known to influence plant growth and uptake of nutrients (Quio *et al.*, 2012; Njira and Nabwami, 2013). Research in farming systems has shown that adoption of conservation agriculture helps to improve biodiversity in the natural and agro-ecosystems (Friedrich *et al*., 2012).

Studies have shown that farming systems promote prolification of soil microorganisms that possess beneficial attributes such as; production of pherohormones, conversion of complex organic substances, pesticide degradation, bio pest control, plant growth promotion and phosphate solubilization (Bhattacharyya and Jha, 2012). Soil fungi that are the most affected by farming practices, and have the ability to produce a broad assortment of extracellular enzymes, capable of breaking down all types of organic matter and modulate the balance of nutrients for maintaining soil health (Waqas *et al*., 2014).

Rhizobia and Mycorrhiza are also found in significant levels in regenerative farming systems and in virgin soils.

Arbuscular mycorrhiza fungi which are of agricultural importance particularly in colonizing and changing the morphological and physiological abilities of crops to absorb nutrients and provide crops the capability to survive against different abiotic stresses (Zhang *et al*., 2011; Maurer *et al*., 2014). Other microorganism highly affected by changes in farming systems are the Arbuscular mycorrhizal AM fungi that enhance absorption of P in deficient soils and can assists in the uptake of water and nutrients by plant and also aid in the improvement of plant growth and survival under drought stress (Zhang *et al*., 2011).

Arbuscular mycorrhizal (AM) fungi in soil samples known to improve rooting and plant establishment, nutrient cycling, plant tolerance to stresses and increased uptake of low mobility ions by crops (Quio *et al.*, 2012) are also affected by farming practices. Mycorrhiza fungi can greatly improve crop yields by increasing the phosphorus uptake by plants and can also enhance the uptake of zinc and copper. Studies have shown that, (Njira and Nabwami, 2013). Studies have shown that, farming systems characterized by minimum soil disturbances and less application of inorganic fertilizers usually have positive effects on MF, and therefore plants may benefit more from MF in such farming systems (Njeru *et al.,* 2014). This trend has also been demonstrated in other studies that have shown significant differences in community structure and diversity of MF in soils, between tilled and reduced or no-tillage farming systems (Kohl *et al.,* 2014). These benefits are required for sustainable, low-input farming systems that don't rely fully on agrochemical to maintain soil fertility and plant health (Maurer *et al*., 2014).

Plant growth promoting bacteria (PGPB) in the plant rhizosphere such as; acidobacter, azospirillium, azotobacter, bacillus, burkholdria, enterobacter, erwinia, flavobacterium, rhizobium and serrotia were found to favour regenerative farming systems, (Akram *et al*., 2017).

Bradyrhizobium *spp,* esorhizobium *spp,* pirellula, nitrospira, nitrosospira species which have been shown to form nitrogen-fixing symbioses with leguminous crops (Lammel *et al.*, 2018). According to Njira and Nabwami, (2013), *Streptomyces* species are important group of soil bacteria capable of producing plant growth promoting substances, *thiobacillus* strains adapted to solubilizing the unavailable form of phosphorus and to enhance the fertility and productivity of soil in agricultural system were also identified. Farming ativities have been shown to affect *Actinomyces spp. in soils.*

Actinomyces spp. have the ability to grow hyphae like fungi that support decomposing of more resistant organic materials such as chitin in low pH (Van Hop *et al.,* 2011). In analyzing of microbial diversity, Dowd and Callaway, (2018), recommends the use of quicker non-culture methods that are more efficient and quicker and can investigate a wide range of microbial genomes. The old methods of soil microbial determination are slow and can only culture about 1% of the total number of microorganisms under laboratory conditions. Various culture-independent methods are able to isolate the total DNA from soil samples by identifying the desired conserved gene, through amplification by DGGE-PCR to generate distinguished banding patterns, (Muyzer *et al.,* 1993). The next generation sequencing (NGS), discovered recently and which has increased speed and efficiency in genomic data generation is now popular in metagenomic analysis (Dini-Andreote *et al*., 2012; Venter *et al*., 2016). Next generation sequencing method was preferred in this study for its efficiency and speed in identifying microbial genomic information from the agricultural soils in the study area. Findings will provide important information on microbial richness in soils where conservation and conventional farming systems have been adopted for some time by farmers (Kaumbutho and Kienzle., 2007).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study Area

Laikipia County is located on the leeward side of Mt. Kenya and the Aberdare ranges, between latitudes 0°17'S and 0°45'N and longitudes 36°15'E and 37°20'E. The county has three administrative units namely; Laikipia East, Laikipia North and Laikipia West (Republic of Kenya, 2013) (Figure 3). The main livelihoods in the county are pastoralism, mixed farming and marginal mixed farming. The study area is located in Laikipia East and North sub-counties, starting from Umande ward in the eastern, N00.04423-N00.08516; E037.06823-E037.20538; to Ngobit ward in south-eastern part, S00.07958- S00.13260; E036.57029-E036.946990 (Jaetzold *et al*., 2006). It represents a wide range of climatic, agro-ecological and socioeconomic conditions with areas of both high and low agricultural potential.

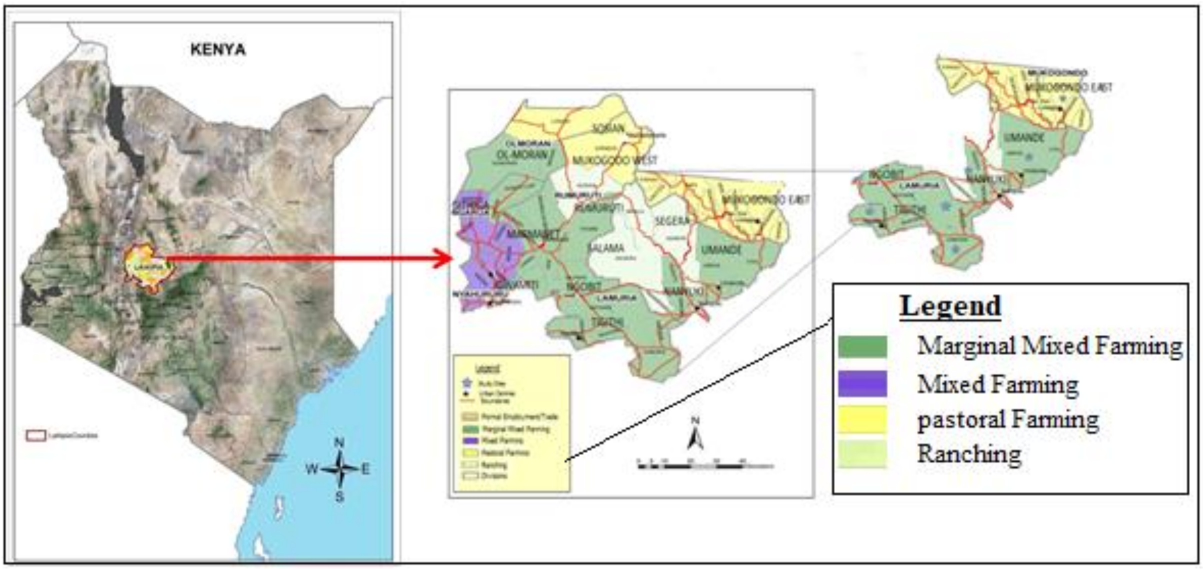

Figure 3. Map of Laikipia Showing Original Sites Where Conservation Agriculture Was Promoted (marked with *) In the Extrapolated Map (County Agriculture Department Report, 2013).

The selected study areas included; five wards in Laikipia East and Laikipia North sub-counties. According to Gitari *et al*., (2014), the dominant soil types found in (wards) in the study area vary from one agro-ecological zone to another. There are two main types of soils in Laikipia and which are also widespread in other parts of Kenya. The first one is the black cotton soils (vertisols) that have origin from volcanic origin and which demonstrate high levels of productivity, with high dressing of clay and silt but characterized by poor water drainage and marked shrink and swell dynamics (Soil AEZs Of Laikipia, 2023). The other category of soils are red sand soils (ferric and chromic luvisols) that are basically sandy, friable loam and originate from metamorphic rocks and though typically low in primary productivity than black cotton soils, are the most salient in the study area, and support crop farming to the majority of farmers (Pringle *et al*., 2007).

Farming in the study area is mainly rain fed and water for farming purposes is mainly rainfall. Rain water is inadequate and is unable to sustain crop cycle from planting to harvesting, for the major crop cultivated by farmers which include short season varieties of maize (Z*ea mays* L.) and beans (*Phaseolus vulgaris* L.), and which take between 3 to $3^1/_2$ months to mature and which require adequate soil moisture condition at the time of planting and at the tasselling and grain filling stages. Some of the main maize varieties grown by farmers in the study area are; HB 511, 512; PH 04, while beans varieties included; Nyota beans, Angaza Beans GLP 1127 (Improved Mwezi Moja), Beans GLP 2 (Rosecoco), Beans (Wairimu Dwarf) and Cowpeas (Kenkunde). Maize crop is especially sensitive to moisture stress at 45-60 days after seeding which coincides with the time of flowering and grain filling stage (Kenya Seed Co, 2010).

The climate data for the study area is shown in table 2. The data that was captured include; temperature, dew point, humidity, wind speed, pressure, for the period between 2010 -2020. The data selected covers the period between March to May 2019 and 2020, covering the four cropping seasons during which the study was carried carried out (Weather And Climate: https://weatherandclimate.com/laikipia/may-2020.).

Table 2. Climate Data for the two growing seasons (LR and SR) in 2019 and 2020.

	2019			2020		
	March	April	May	March	April	May
MeanTemperature (^{0}C)	20.32	18.87	17.81	20.32	18.87	17.81
Mean Humidity (%)	60.29	69.58	81.03	60.29	69.58	81.03
Mean Wind Speed (Kph)	5.16	4.45	6.26	5.16	4.45	6.26
Mean Precipitation (mm)	2.98	5.87	6.55	2.98	5.87	6.55

Adopted from: https://weather and climate.com/laikipia/may-2020.

Rainfall is bimodal and unreliable with an annual average of 400mm - 750mm and average temperature of between 16 - 30°C (Laikipia CIDP; 2018-2022).

According to this information, the mean monthly rainfall in the five selected wards (sites), ranged between 350-600 mm per year, which are lower than the county mean monthly rainfall range of between 400-750 mm. In view of this, soil moisture availability to crops should coincide with the critical stage of water requirement (Kenya Seed Co, 2010).

Data on specific sites based on 2019-2020 rainfall figures from meteorological weather stations and Social Hydro-logical Information Platform (SHIP) is shown in figure 4.

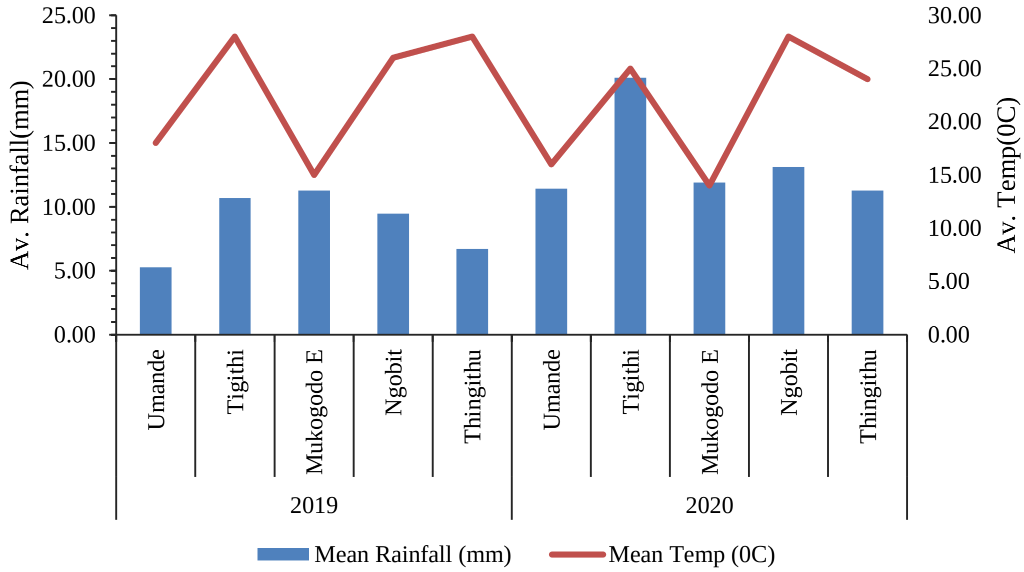

Figure 4. Bar graphs showing the mean annual rainfall, line graph representing mean temperature in study sites. (Source: Meteorological department & CETRAD, portal, 2018; Weather and Climate: https://weather and climate.com/Laikipia/may-2020).

The crop farming calendar from planting to harvesting in the study area is shown in Table 3.

Table 3. Crop Farming Calendar in the Study Area.

Dry		*Long Rains*			Dry				*Short Rains*		
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
H	LP_1	P_1	W_1	W_2	H	N-A	N-A	LP_2	P_2	W_1	W_2

Key: LP_1, LP_2= Land preparation for 1st and 2nd cropping cycles; W1, W_2 = Weeding for first and second cropping cycles; H = crop Harvesting; Wet = Wet period and N-A = No Activity. (Adopted with modifications from; Huho *et al*., 2012).

FAO, (2010) describes AEZs as land units named on the basis of combinations of soil, land forming systems and climatic characteristics. The major agro-ecological zones (AEZs) described by Jaetzold *et al.*, (2006), include; LH-Lower Highland zone, UM-Upper Midland zone, LM-Lower Midland zone. Data on soil AEZs for Kenyan soils based on FAO soil classification system for the study area.

The biophysical characteristics of the study sites in Laikipia East and Laikipia north sub-counties are shown in Table 4.

Table 4. Biophysical characterization of soils in the study area

Sub-county	Ward	AEZ	Temp ^{0}C	Altitude (Masl)	Annual Rainfall range (mm)	Soil Class	Soil Element deficiency⁑	Soil Element Toxicity⁑
Laikipia north	Mukogodo East	LH5, LH6	16-29	1833.98-2219.31	400-1000	Vertisols and Alfisols	N, P, S, most micro	Fe
Laikipia East	Umande	LH5, LH6	16-28	1832.91-2142.51	400-800	Mollisols	Mo	-
	Thingithu	LH4, LH5	16-26	1791.26-1931.93	400-750	Mollisols	Mo	-
	Tigithi	UM5, LH5	18-30	1803.00-1980.00	400-750	Alfisols, Mollisols, Vertisols	N, P, Most micro nutrients	Fe
	Ngobit	UM, LH5, LM	22-30	1836.00-2250.73	400-750	Vertisols, Mollisols, Ultisols	N, P, S, Mo, Ca Mn	Al, Fe
	Umande	UM5 ,LH5,	16-28	,,	400-750	Mollisols	Mo	-

USDA, (1975); ⁑Jaetzold *et al.*, 2006); based on FAO Classification System. Key: N=nitrogen, P=phosphorus, Ca=calcium, Mn=manganese, Fe=iron, Al=aluminium, S=sulphur and Mo=Molybdenum.

3.2 Characterization of Farmers Field Schools

The names, location and membership of the farmers' groups trained in conservation agriculture curriculum is listed in Table 5.

Table 5. CA - FFS Groups in the Study Area (2008 - 2018).

Farmers Field School (FFS)	Location	Membership in 2008			Membership in 2013			Membership in 2018		
		M	F	Tot	M	F	Tot	M	F	Tot
Jikaze Kilimo Hifadhi	Ngobit	4	3	7	27	11	37	27	15	42
Mwiyetheri CA group	Ngobit	8	8	16	26	16	48	26	13	39
Marura CA group	Thingithu	5	4	9	38	12	40	38	17	55
Kalalu Agric Group	Umande	3	2	5	17	9	23	17	12	29
Mutirithia CA group	Mukogodo E	16	8	24	24	22	81	24	9	33
Magutu CA group	Tigithi	12	7	19	32	19	75	32	8	40
Mazingira CA group	Tigithi	20	10	30	37	26	92	37	16	53
Kileleshwa CA group	Tigithi	12	12	24	42	27	85	42	13	55
Total Farmers		80	54	134	243	142	481	243	103	346

Source: Laikipia County Official Agricultural Report, 2018. CA = conservation agriculture; M = male; F = female; Tot = total

The information highlights farmer adoption and practice of CA principles and other farming practices employed by CA farmers (adaptation). The years between 2008 - 2013, were characterized by a period of aggressive growth in farmers field schools (FFS) membership and adoption of CA with members growing from 134 in 2008 to 481 in 2013, but later declined from 481 in 2013 to 346 members in 2018. This change in membership is thought to be due to new farmers adopting CA and joining FFS after 2007, but the momentum in CA uptake dropped among farmers, with the number of those adopting CA declining to 346 by 2018. African conservation tillage (ACT) (2016) attributes this drop in membership to lack of commitment to CA adoption by farmers.

This information is key in understanding CA practices, among other farming practices and decision-making processes as a way of evaluating the link between promotion and technology adoption of CA.

3.3 Criteria for Selecting Study Area and Participating Farmers

The study area was purposively selected to include sub-counties and wards where conservation agriculture had historically been practised since its introduction in the study area. The sites consisting of Laikipia East and Laikipia North sub-counties targeting Ngobit, Tigithi, Thingithu and Umande wards in Laikipia East sub-county and Mukogodo East ward in Laikipia North sub-county were selected. These areas fall under different agro-ecological zones (AEZs) (Huho *et al.*, 2012) and have a variation in soil types and climate. The soil types were classified according to FAO classification systems.

According to Laikipia county department report, (2013), the number of registered farmers during farmer targeting for farm inputs in 2010 were; 7,262 farmers, out of which 2,000 had previously been trained on conservation agriculture practices by African conservation tillage (ACT) and Alliance for green revolution in Africa (AGRA, 2014; (ABACO, 2012; County agriculture reports). A two-stage sampling design was adopted whereby some farmers were targeted for the field survey and then further sampling to obtain farmers for the administration of questionnaires. The 2,000 small-scale farmers who belonged to farmers field schools (FFS) were conveniently targeted for the field study, since they had adopted CA and had a portion of conventional farming (CF) in their farms (Laikipia County Agriculture Report of 2013). In the first criteria, farmers were sampled based on the following attributes: (i) farmers who had participated in CA training for farmers' field schools; (ii) farmers who were actively practising all the three principles of CA (minimum soil disturbance, continuous permanent soil cover and crop rotation/diversification) as outlined by FAO (2019); and (iii) farmers practising both CF and CA farming.

Under this criterion, 332 farmers qualified for the study, and the sample of 332 farmers used to administer questionnaires for data collection on adoption of farming practices. Further sampling of farmers for field soil sampling and collection was done by proportionate stratified random sampling (PSRS), providing final sample of 30 farmers based on ward (strata) population. The formula for the calculation of sample size according to Haque, (2010) is as indicated in Equation 1.

Equation 1: …… $nh = (Nh / N) * n.$

Where: nh = stratum sample, Nh = farmers' population in a stratum, N = Total farmers population and n = targeted population sample. The computation of PSRS is represented in Table 6.

Table 6. Sample Size Determination For Farm Interviews And Soil Collection

Ward (Site)	FFS Group	Farmers' Population (2015)	Creteria Sample	PSRS Sample (S=stratum p/total P * total target sample)	%
Mukogodo E	Mutirithia	254	52	4.7	*15.7*
Umande	Kalalu Agric	248	34	3.07	*10.2*
Ngobit	Jikaze Kilimo	264	66	5.96	*19.9*
	Mwiyetheri	236	26	2.35	*7.8*
Tigithi	Magutu	240	58	5.24	*17.5*
	Mazingira	248	65	5.87	*19.6*
	Kileleshwa	250	13	1.17	*3.9*
Thingithu	Marura	260	18	1.63	*5.4*
Total		2,000	332	30	*100*

FFS = Farmers Field Schools; PSRS = Participatory Stratified Random Selection. *Source*: Laikipia County Agricultural Office unpublished data of 2015-2017.

The two-stage sampling ensured that, all the factors were well represented in the sample to improve accuracy as compared to one-step method that does not change the total number of observations made, and also ensured that farmers were selected proportionate to their population in each sampling stratum (Nyirahabimana, 2011).

The sampled farmers were approached and willingly agreed to offer their farms for the collection of soil samples for use in determining the effects of land management practices under CA and CF farming systems.

3.4 Data Collection on Household Adoption of CA Practices

Qualitative data on farming practices was collected using questionnaires administered to 332 heads of households directly involved in farming practices. Questionnaires were written in English, but sections requiring further clarification during field administration were done in Kiswahili or local languages. Data was collected on farm size, duration of farming, education, age, gender, providers of extension services, farm funding, farm' decision, farmer perception of CA principles and practices, technology transfer, adoption and adaptation practices, annual crops cultivated, farmer experience, reason for farming and tools and implements used in CA. Data on other farming practices such as soil and water conservation, crops grown, crop residue utilization and farm tools used by farmers was also collected. To ground truth and clarify on collected information on farming practices, field visits, observations and use of key informant interviews were used. Data collected comprised of primary and secondary data which included individual interviews, focus group discussions (FGDs), data mining from records and researcher observations.

Secondary data on historical documents was used to examine farming systems and climatic data (temperature and rainfall) in the study area. Documented CA adoption and acreage data was collected from the MOA offices in Laikipia East and North sub-counties from 1997-2019. Data on rainfall and temperature, thought to influence soil moisture levels was based on the 2019-2020 figures from meteorological weather stations and Social Hydrological Information Platform (SHIP).

Monthly climatic data obtained from Kenya Metrological Department, Nairobi (KMD) included temperature (^{0}C) and rainfall (mm) from 1997 to 2019 for the adjacent stations in Laikipia County. Other sources of data included journal articles, government reports, County strategic plans, County abstracts and books which gave background information on conservation agriculture practices in the region.

3.5 Selection of Farms and Soil Sampling

The sampling frame consisted of County (Laikipia), sub-counties (Laikipia East and north) and wards (Tigithi, Ngobit, Umande, Mukogodo East and Thingithu). To select farms to determine the effect of farming systems on soil properties, experimental design consisting of sampling plots measuring 3mx3m, demarcated on farms adopting Conservation Agriculture (CA) and Conventional farming (CF) systems was done. Soil samples were also collected from a fallow reference land (RL) bordering each farm and which had not been tilled for at least three years, thus providing baseline soil samples for control purposes (Figure 5).

Figure 5. Field Soil Sampling Photos Taken In Different Farming Systems And Sites.
A = Conventional farming field, B = Conservation agriculture field and C = Reference land

Each farming system provided three plots' replicates, where soil sampling from randomly selected sampling points in each plot within CA, CF and the reference land (RL) was done. This approach substituted space for time since each ward was located such that differences in geological, topographic and climatic conditions were negligible.

Under these conditions, any differences in soil properties were assumed to be attributed to the differences in farming practices of each farming system (Nyirahabimana, 2011). The classification of different farming systems practised by farmers in the study area is shown in Table 7.

Table 7. Description of the sampling units within the selected farms in the study area

Sampling fields	Land use description	Land use history
Conservation Agriculture (CA)	Minimal land disturbance during land tillage, planting and weeding, use of cover crops and crop rotation.	Has been practiced for over 15 years
Conventional farming (CF)	Intensive soil disturbance during land Tillage, mono-cropping.	Has been practised for over 20 years
Reference land (RL)	Areas left fallow to regenerate, limited or no cropping or grazing activities	No agricultural activities for at least 3 years

Land use management practices in different farming systems and the reference land (FAO, 2019; Biamah, 2005).

3.6 Soil Sampling and Analysis

Except for the soil sampling for the analysis of soil moisture and organic carbon which were done during the 2019 and 2020 planting seasons, all other sampling were done during the 2019 planting season. The soil samples were purposively maintained at one composite sample for every 3m x 3m plot. There were three such plots demarcated in a field of conservation agriculture (CA) farming system and a similar number from conventional farming (CF) and a bordering reference land (RL) that had not been cultivated for at least 3 years and used as a control. Soil sampling was done in a zigzag pattern on randomly selected 10 points from the 3m x 3 m plots within the sampled farms practising different farming systems.

Soil samples were collected at 20 cm deep which is the rooting depth in most annual crops (Kenya Seed, 2010) using a metallic soil auger of 5-cm diameter, a total of 9 composite samples were collected; with each farm providing 3 from CA, 3 from CF and further 3 from RL. Soil samples collected from the respective sampling points in each plot and replicates were mixed up to form a representative (composite) sample for the analysis.

Soil samples weighing about 300g from each plot or replicate were placed in ziplock bags and transported to the laboratory for analysis. The samples were air-dried, ground and sieved to pass through a 2mm sieve for subsequent chemical and physical analysis while a sub sample was finely ground for organic carbon analysis using standard chemical analytical techniques. Soil sampling methods and the number of samples for the determination of each parameter differed depending on the number and methods used. A total of 3,780 composite samples collected for the determination of various soil parameters were distributed as per Table 8.

Table 8. Soil sample distribution based on soil parameters determined

Soil parameter	Farms	Farming systems	Plots or replicates / FS	No. Of Seasons	Data collection / season	Total number of samples
Soil Moisture	30	3	3	4	3	3,240
Soil Bulk Density	30	3	3	1	1	270
Soil Texture, nutrients	30	3	3	1	1	270
Total No. of Samples						3,780

3.6.1 Soil Moisture Determination

To ensure that there was adequate data for the monitoring of soil moisture, separate soil samples weighing about 500g each were collected from selected sampling points of farms that had similar crops, agricultural management practices and agro-ecological zones. Soil sampling was done thrice per season, at 25, 50 and 75 days after seeding (DAS).

Soil samples were collected from 3x3m plots demarcated in 30 farms practising both conservation agriculture (CA) and conventional farming (CF) systems for 2 years during the 2019/20 long and short rainy (LR, SR) seasons. Soil samples were also collected from reference land (RL). After collection, samples were placed in aluminum cans with lids, and transported to the laboratory for further analysis. Soil moisture was determined by the oven drying method as described by Okalebo *et al.*, (2002). Fresh weighed samples were oven dried for 48 hours at 105^0C until a constant weight. Gravimetric water content of each sample was calculated as the percentage of the mass of water per mass of dry soil (Shukla *et al*., 2014), and percentage soil moisture content determined using the formula presented as in Equation 2.

Equation 2*: …* $MC\% = (WTw - WTd)/WTd * 100.$
Where; MC(%) = Percentage Moisture Content, WTw = Weight of field wet sample, WTd = Weight of oven dry sample.

The sampling intervals for soil moisture determination was justified since beans and maize varieties mentioned earlier require adequate soil moisture condition at the time of foliage, flowering and grain filling stages and it is at this stages that the crops are most sensitive to moisture stress (Kenya Seed Co, 2010).

3.6.2 Determination of Soil Bulk Density (BD)

The collection of soil samples for determination of soil bulk density was done once during the dry period, just before the onset of 2020 October - November long rainy (LR) season. Undisturbed core samples for bulk density were obtained using the core method according to Blake and Hartge (1986). A total of 270 soil samples were collected from 30 farms each practising both farming systems (CA, CF) and from a reference land (RL) in a 3x3 m plots using a metal core ring sampler of 5cm- diameter and 10cm height was used to pick the samples. The metal ring core sampler was driven into the soil using a wooden block at the depth of 0-20 cm and then excavated using a trowel.

Excess soil was removed with a flat bladed knife, and then the core contents for each depth emptied in a separate paper bag, labeled and delivered to the laboratory. Soil samples were first weighed to record the weight of wet soil samples. Soil bulk Density (BD) was calculated as the weight (g) of the soil sample divided by the volume of the sample (cm3) as shown in Equation 3 below;

Equation 3: ……………. $BD\ (gcm - 3)\ =\ Wt(g)\ /\ Vol(cm3).$

Where: BD = bulk density (gcm^{-3}), wt = weight of soil in the sampler (g), Vol = Volume (cm^{3}) of the dry soil sample.

3.6.3 Soil Sampling For Determination Of Soil Attributes

Soil sampling for the determination of soil texture, pH, N, P, K, Cal and Mg was done once during the dry period, just before the onset of 2020 October - November long rainy (LR) season. Soil sampling was done according to Laboratory methods of soil and plant analysis: A working manual (Okalebo *et al*., 2002). A total of 270 soil samples weighing about 500g each, were collected from 30 farms each practising both farming systems (CA, CF) and from a reference land (RL) in a 3x3 m plots from the topsoil (0–20 cm) layer Soil sampling for the determination of soil bacteria and fungi were separated from the rest and stored in cooler boxes at -20°C until DNA extraction.

3.7 Laboratory Soil Analysis

Different laboratory soil analysis were performed following different manufacturers' protocols and procedures for the various soil parameters.

Activities during laboratory soil analysis are shown in Figure 6.

Figure 6. Images Taken During Laboratory Soil Analyses. Photo D: measuring of soil bulk density (core sampler Method), E: Chemical analysis of soil elements and F; Electrophoresis MIDI unit for performing electrophoresis of DNA metagenomics.

3.7.1 Analysis of Soil pH (H20)

This was measured using a 1:2 water extraction. An air-dried soil sample (20 g) was put into a 100ml plastic beaker followed by 50ml of distilled water. The mixture was shaken for ten minutes using an electric shaker and left to settle for thirty minutes. Stirring of the mixture was done once more for two minutes and the pH of the suspension measured using a pH meter. Soil samples with pH values less than 6.0 were further analyzed using lime requirement test. Lime requirement test, is a test of soil lime buffering capacity (LBC) and was done to determine the amount of soil acidity that must be neutralized to raise soil pH (Mehlich, 1976). In other words, acidic soils with a high LBC would require more lime (greater resistance to pH change) than those with lower LBC. This information is important when providing advice to the farmers on the amount of pure lime (CaCO3), needed to raise soil pH of their soils (Huluka, 2005).

3.7.2 Analysis of Exchangeable Cations

The dried soil samples were extracted in a 1:5 (w/v) with a mixture of 0.1N HCL and 0.025N H_2SO_4 solution.

Five (5g) of air dry (2mm) soil was weighed into a clean plastic bottle and 100ml of 1M ammonium acetate solution (NH4OAc) added and contents shaken for 30 min using mechanical or electric shaker and filtered through No. 42 Whatman filter paper to obtain a soil extract. The use of hydrochloric acid was to serve as a replacement for most of the exchangeable metal cations. In field situations, the sulphate anions in an acidic medium fulfill the replacement of soluble phosphorous available to plants which is held in exchangeable forms. The concentration of H_2SO_4 was restricted to about 0.03M, since this approaches the maximum concentration of calcium sulphate solubility. Thus soils with high amounts of Calcium tended to precipitate out as $CaSO_4$ and escaped measurement. Potassium, Ca, and Na were determined by flame photometry while P, Mg and Mn were determined by calorimetric procedures.

3.7.3 Analysis of %Soil Nitrogen

Percentage soil Nitrogen was measured using the Kjeldahl method. This method was preferred since it determines both the organic and inorganic nitrogen availability in the soil, which is used as a guideline for N application in farms. The Kjeldahl method involving a three-step approach to the quantification of nitrogen was used: digestion, distillation, and titration. Digestion of organic material was achieved by using concentrated sulphuric acid (H_2SO4), heat and K_2SO4 (to raise the boiling point). Boric acid buffer solution was used as a catalyst to speed up the reaction. This process converted any nitrogen in the sample to ammonium sulfate.

The digestate was neutralized by the addition of NaOH, which converted the ammonium sulfate to ammonia, distilled off and collected in a receiving flask of excess boric acid, forming ammonium borate. The residual boric acid was then titrated with a standard acid with the use of a suitable end-point indicator to estimate the total nitrogen content of the soil sample.

3.7.4 Analysis of %Soil Organic Carbon

The Walkley-Black method, (1934) was used for determination of soil organic carbon. The principle method used in this study is a wet oxidation procedure using potassium dichromate with external heat. The procedure is rapid and is adapted for routine analysis in a soil testing laboratory by way of wet oxidation of organic C by acidified dichromate: -

Equation 4: ………….. $2Cr_2O_7^{2-} + 3C + 16\ H^+ \rightarrow 4Cr^{3+}\ 3CO_2 + 8\ H_2O^2$.

To ensure complete oxidation of all organic C in the soil sample, it was necessary to heat the reaction at 150^{o}c for 30 minutes. The colour metric method was used to determine the amount of organic C in samples by the amount of chromic ion (Cr^3) produced in the above section. A sample weighing 1.0g was ground to pass through a 2 mm screen, into labeled digestion tubes. If the soil colour was dark or suspected to containing high organic matter, only about 0.5 g of the samples was used. Standard samples, reagents and blanks were included in each analysis. Duplicate samples after every 10 samples in a batch were also included for quality control. Ten (10) ml of 5% potassium dichromate solution was added into both standard and sample tubes, and the potassium dichromate allowed to completely wet the soil. Twenty (20 ml) of concentrated 36 N sulphuric acid was transferred into a measuring cylinder.

This was poured in a steady stream into the center of the soil-dichromate mixture. There was an immediate reaction and considerable heat was produced: it was placed on a sheet of asbestos and allowed to cool for about 20 minutes. Distilled water (DW) was added to bring the volume to about 200 ml. Approximately 5.0 ml 85% orthophosphoric acid (H_3P0_4) and about 5.0 ml of diphenylamine sulphonate indicator were added. Titration was done with 0.5 N ferrous sulphate (or ferrous ammonium sulphate), the exact normality of which was obtained by titrating 10.0 ml of dichromate in a blank. As the end point is approached the turbid dark blue colour became greenish, changing to a clear pale green quite sharply at the end point itself. Percent soil organic carbon in the sample was formulated as outlined by Walkley & Black, (1934); using the formula below;

Equation 5: …………… $OC = T \times 0.2 \times 0.3 / Wts.$

Where; T = titration volume; Wts = Sample weight

3.7.5 Analysis of Soil Available Phosphorus.

The combination of HCl and H_2SO_4 as described in Mehlich Double Acid method was used with the intention of recovering easily acid-soluble forms of phosphorus, largely the Ca-phosphates and a portion of the Al and Fe phosphates. The dried soil was extracted in a 1:5 (w/v) with a mixture of 0.1N HCL and 0.025N H_2SO_4 solution. The hydrochloric acid served to replace most of the exchangeable metal cations held in exchangeable forms. The concentration of H_2SO_4 was restricted to about 0.03M, since this approaches the maximum concentration of calcium sulphate solubility. A 2.5g of air-dry soil (2mm) was weighed into a 250ml shaking bottle and placed on a mechanical shaker for 30 minutes. The suspension was filtered through the Whatman paper No. 42, and pipetted 10ml of the sample filtrates and 2 reagent blanks into a 50ml volumetric flasks and added 5ml of 0.8M boric acid followed by 10ml of the ascorbic acid.

Each flask was then filled to the 50ml mark with distilled, the contents shaken and then left for one hour. The absorbance of the solution was measured by calorimetric method, at wavelength setting of 540nm, and the P concentration was expressed in mg kg^{-1} or ppm.

3.7.6 DNA Extraction, Concentration and Purity

Soil samples collected for the analysis of bacterial and fungal diversity were packaged and stored in refrigeration at -4^{0}C, to slow down microbial activity until laboratory analysis.

Extraction of soil DNA was carried out at Kenyatta University molecular laboratory. The total DNA was extracted using PureLink^{TM} Microbiome DNA Purification Kit protocols from Thermo Fisher Scientic Inc. About 0.5 gm of soil sample was added to 1.5mL sample grinding tubes with glass beads. The extraction process included a bead beating step, to help break open microorganisms within the soil in order to maximize on the amount of DNA extracted. This was followed by cell lysis and purification of the genomic DNA from the other soil biomolecules. The quality and quantity of DNA was determined using Eppendorf BioPhotometer® D30 to ensure that sufficient DNA was present prior to amplification.

3.7.7 Confirmation of Microbial DNA

After DNA extraction and purification, electrophoresis of DNA-eluates was performed in 0.8% agarose gel in TBE buffer solution (pH 8.3) containing ethidium bromide (0.4 mg/L), using Electrophoresis Unit MIDI 1 (Germany). A constant electrical current of 90 mA was passed through the gel for 30 minutes to separate DNA fragments between 100 bp and 25 kbs.

After electrophoresis, the stained gel was photographed using UV transilluminator Bio-Doc-It™ System (UVP laboratory instruments, (USA) at 312 nm to confirm availability of DNA fragments (Figure 7), before shipping the raw DNA to molecular research lab, USA for apmlicon generation and sequencing.

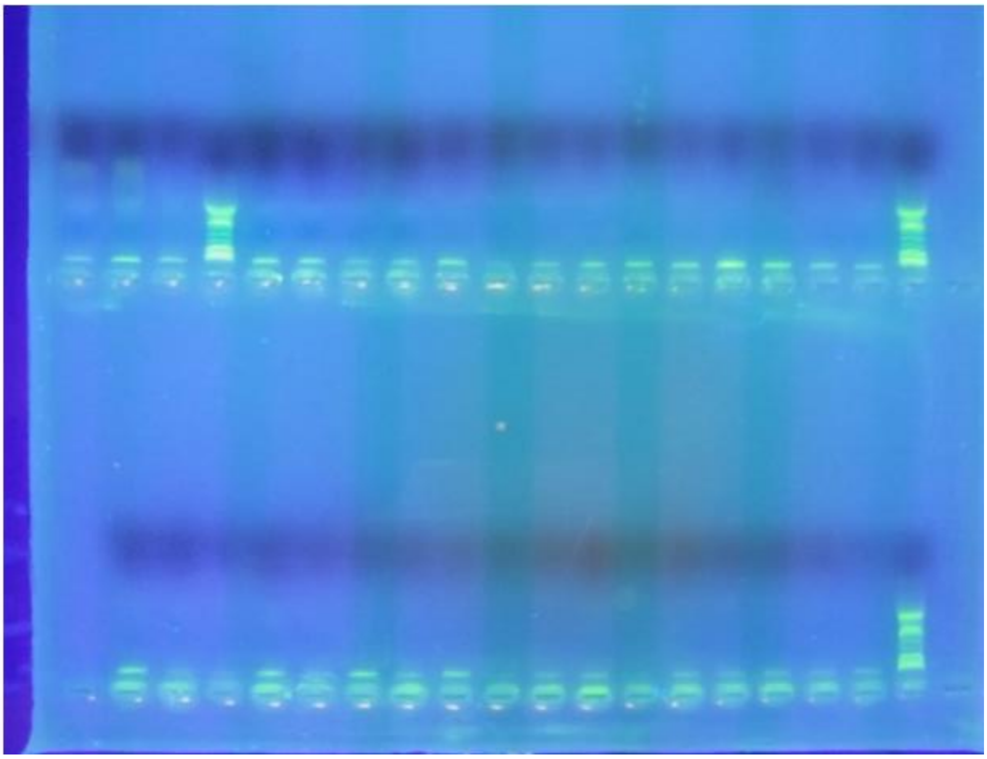

Figure 7. A Photograph of Post Electrophoresis Gel Image, confirming availability of microbial DNA.

3.8 Microbial Data Processing

The Q25 sequence data derived from the sequencing process was processed using the MR DNA ribosomal and functional gene analysis pipeline (www.mrdnalab.com, MR DNA, Shallowater, TX). Sequences were depleted of primers, then shortened to sequences (< 150bp) and sequences with ambiguous base calls removed. Sequences were filtered using a maximum expected error threshold of 1.0 and dereplicated (Glassing *et al*., 2015).

The dereplicated or unique sequences were deionised; unique sequences identified with sequencing or PCR point errors were removed, followed by chimera removal, thereby providing a deionised sequence or OTU. Final OTUs were taxonomically classified using BLASTn against a curated database derived from NCBI (https://www.ncbi.nlm.nih.gov/) and compiled into each taxonomic level into both "counts" and "percentage" files. Counts files contained the actual number of sequences while the percent files contain the relative (proportion) percentage of sequences within each sample that map to the designated taxonomic classification. After stringent quality sequence curation, a total of 698805 sequences were parsed and 606938 were then mapped to zOTUs. A total of 604699 sequences identified within the bacteria and archaea domains were utilized for final microbiota analyses. The average reads per sample was 30234. For alpha and beta diversity analysis samples were rarefied to 20000 sequences.

3.8.1 Beta Diversity Analysis

Beta diversity comparison of the communities of microbes as a whole taking into account different organisms in the samples and how those organisms are related phylogenetically was done. The microbial community structure was analyzed using weighted UniFrac distance matrices (Lozupone and Knight, 2005). Analysis of the microbial community structure was performed by creating individual phylogenetic trees, without regard for taxonomy, for each sample then statistically evaluating each tree among each sample.

3.8.2 Amplicon Generation and Sequencing

Amplicon generation and sequencing was done using modern methods, the next generation (NGS) Illumina's MiSeq technology platform (bTEFAP®) originally described by Dowd *et al.,* (2008) and was performed at Molecular Research (MR DNA) labs, 503 Clovis Road Shallowater, TX 79363, United States (Dowd and Callaway, 2008; Edgar, 2010; Swanson, and Dowd, 2011).

The DNA, ITS (internal transcribed spacer) and 16S segments of rDNA targeting fungal and bacterial communities respectively were used on the genomic soil DNA. Soil bacterial community was assessed using Illumina Miseq (2 x 150 bp) sequencing of the 16S rRNA gene with two representative modules of CA and CF farming practices (n = 2). For bacterial identification, PCR amplification was performed using primer pair, 515F GTGCCAGCMGCCGCGGTAA/ 806R GGACTACVSGGGTATCTAAT, targeting the V4-V5 hypervariable region (Klindworth *et al.*, 2013) of each sample on the Illumina NovaSeq with methods via the bTEFAP® DNA analysis service (Swanson, and Dowd, 2011).

For fungal identification, ITS universal primers ITs 1 and ITS 4 were used, according to Dowd and Callaway. (2018). The –ul of DNA template was mixed with –ul of HotStarTaq and –ul of Master Mix (Qiagen Kit, Valencia, CA). The PCR was set under the following conditions: 95^0C for 10 minutes, followed by 35 cycles of 95^0C for 30 seconds; 53^0C for 40 seconds and 72^0C for 1 minute; after which a final elongation step at 72^0C for 10 minutes was performed. Success of amplification was confirmed through agarose gel electrophoresis.

3.9 Statistical Data Management

Statistical analysis of the laboratory findings was done to compare farming systems and to determine the effects of different farming practices on soils in Laikipia County. Statistical analysis of farming practices data was analyzed for descriptive statistics at $p \leq 0.05$ using IBM SPSS Statistics version 25. Results on the effects of farming systems on selected soil properties was done using *R-program (2022),* with analysis of variance (ANOVA) and post hoc family wise comparisons test for significance differences between factors and results presented using tables and bar charts.

Test statistics were significant at $p \leq 0.05$. Different soil textural classes were determined according to the relative percentages of sand, silt and clay, based on USDA soil texture triangle. Statistical analysis for the microbial data was performed using a variety of computer packages including XLstat, NCSS 2007, “R” and NCSS 2010. Alpha and beta diversity analysis was conducted as described by (Dowd, Callaway *et al*. 2008; Edgar, 2010; Eren, Zozaya *et al.*, 2011; Swanson, Dowd *et al*., 2011) using Qiime 2 (Bolyen *et al*., 2018). Bacteria and fungi diversities were identified from sequencing of extracted soil microbial DNA using next generation sequencing (Dowd, Scott *et al*., 2019). Significance difference was defined at $p<0.05$.

CHAPTER FOUR

RESULTS OF ANALYSIS, INTERPRETATION AND PRESENTATION

4.1 Farming Systems, Adoption and Practices

This chapter presents the results of the findings in four specific objective areas; (i) farming systems adoption and practices, (ii) Soil physical properties (texture, moisture and bulk density) under different farming systems, (iii) Soil chemical properties (total nitrogen, soil organic carbon, available phosphorous and exchangeable cations) under different farming systems and (iv) Soil microbial properties (bacteria and fungi diversities) under different farming systems.

4.1.1 Principles and Practices of CA Adopted By Farmers

Findings of principles and practices employed in farming systems are shown in Table 9. These findings indicate that 33% of farmers employed all the three principles of conservation agriculture (crop cover/residue + crop rotation + no tillage) as advocated for by FAO (2019), while 19% of them employed at least two principles of CA, out of these 13% of them employed, non-retention of crop residue/non-use of crop cover + crop rotation+ none or minimal soil tillage, where 6% of the rest employing crop residue retention/ use of cover crop + crop rotation + soil tillage.

Table 9. Farmers Adoption of Farming Principles and Practices (N=332).

Principle and Practice	No. Of CA Principle(s)	Frequency	%
Tillage+crop rotation+no retention of cover crop/residue	1	6	1.81
Mono-cropping+no cover crop/residue+no tillage	1	8	2.41
Mono-cropping+cover crop/residue+tillage	1	12	3.61
Cover crop/residue+Mono-cropping+no tillage	2	20	6.02
Crop rotation+no cover crop/residue+no tillage	2	24	7.23
Use of crop cover/residue+crop rotation+tillage	2	38	11.4
Use of crop cover/residue+crop rotation+no tillage	3	224	67.4
Total		**332**	**100**

As far as adoption of CA principles is concerned, 7.83% of farmers adopted at least one CA principle, 24.70% adopted at least two principles, while 67.47% adopted all the three principles employed in CA as outlined by FAO, (2019), (retention of crop residue/use of cover + crop rotation + no-tillage of soil). Among those who adopted at least one principle, 1.81% employed crop rotation, 2.41% employed non-tillage of soil, while 3.61 employed crop cover and retention of crop residue. Those farmers who adopted at least two principles of CA, 6.02% employed cover crop/residue and non-soil tillage, 7.23% employed crop rotation and non-tillage of soil, while 11.45% employed use of crop cover/residue retention and crop rotation. Overall, the findings indicated that, the largest number of farmers consisting of over 60%, are committed to practising CA as recommended and only less than 40%, are not practising CA, as recommended by FAO.

4.1.2 Characteristics of Households Practicing Conservation Agriculture

Findings on household characteristics are shown in Table 10. From these findings, land size may be a constraint and limiting factor in agricultural development among smallholder farmers in the study area since only 8% of farmers owned land greater than 4 acres. Majority of farmers (63%), have been in farming for over 15 years, 34% have been in farming for between 10-15 years and only 3% have been in farming for less than 10 years.

Findings showed majority 67% of the farmers (N = 332) belonging to farmers field schools were male farmers, while 33% were female, demonstrating gender disparities in land ownership.

Table 10. Household Characteristics

Variable	Specific variable	Mukogodo East (*n*=4)	Umande (n=5)	Ngobit (n=7)	Tigithi (n=12)	Thingithu (n=2)	Total no. farmers	%No. Of Farmers
land Ownership By Gender	Male	26	39	44	98	16	223	67.00
	Female	16	21	28	36	8	109	33.00
Age (years)	< 35	12	14	21	40	5	92	28.00
	35 - 50	22	39	43	86	16	206	62.00
	>50	8	7	8	8	3	34	10.00
Level of education	Informal	6	6	3	3	1	19	6.00
	Basic	25	17	22	36	6	106	32.00
	Secondary	10	35	46	91	16	198	60.00
	College/University	1	2	1	4	1	9	3.00
Farmer Category	Smallholder farmers	54	62	75	96	37	250	96.71
	Large scale farmers	1	0	2	3	0	6	2.09
	Vulnerable/Disability	1	1	0	0	0	2	2.0958083 1.20
Farm size (ha)	<2.03	28	38	21	22	6	115	83 35.00
	2.42 - 4.05	12	14	47	100	16	189	57.00
	> 4.05	2	8	4	12	2	28	1.1976047 8.00
Years in active farming	<10	2	1	2	6	0	11	9 3.00
	10 - 15	12	25	30	37	9	113	34.00
	>15	28	34	40	91	15	208	63.00

Regarding age of the participating farmers, 28% were aged below 35 years, 62% were aged between 35 - 50 years and those aged over 50 years consisted of 10%. Further, farmers adopting climate smart agricultural (CSA) technologies below 50 years of age consisted of 90%, compared to 10% of those above 50 years of age, indicating the relationship between farmer age and technology adoption, with old age being associated with loss of energy, risk aversion, and short-term investment planning (Christiansen *et al.*, 2011; McCarthy *et al*., 2011).

As far as education is concerned, 32% of farmers had at least basic education, 60% had secondary education, and 3% had college or university education with the remaining 6% having non-formal education. The findings indicated that, most farmers in this study consisting of over 90% had primary and secondary education. The findings also indicated that, most of the farmers adopting farming technologies were in the categories of primary and secondary levels. The farmers in this age bracket are presumed to be young and age may be a contributing factor for fostering of technology adoption and adaptation. There are less than 4% of farmers in the categories of college and university doing farming in the study area. As far as farmer categories are concerned, majority of farmers participating in the study were small scale farmers consisting of 96.71%, followed by large scale farmers at 2.09%, while the vulnerable and marginalized groups (VMGs) members formed only 1.2%.

4.1.3 Farm Financing, Technical Advisory, Crops Grown and Farm Inputs Supply

Results of analysis on farmers' responses on purpose for farming, source of farm financing, accessibility of extension services, crops grown, source of water for farming and farm input supply are shown in Table 11.

Table 11. Farmers' Responses on Farming adoption and Extension Management (n= 332)

Area	Response (s)	Mukogodo East (n=4)	Umande (n=5)	Ngobit (n=8)	Tigithi (n=12)	Thingithu (n=2)	Total farmers	% of total
Why Do You Do Farming?	For Food	24	38	39	91	14	206	62
	For Income	13	16	25	38	8	100	30
	Others (unspecified)	5	6	8	5	2	26	8
Who Funds You?	Self-Funding	29	42	56	111	14	252	76
	County govt (partial)	10	12	12	18	8	60	18
	Others (unspecified)	3	6	4	5	2	20	6
Source of Extension?	Government Staff	26	39	47	118	14	244	73
	Private Extension	7	8	9	10	5	39	12
	Others (unspecified)	9	13	16	6	5	49	15
Annual Crops Grown?	Maize & Beans	37	56	69	128	20	310	93
	Maize, Beans & Others (unspecified)	5	4	3	6	4	22	7
Supplemental Irrigation Done?	YES	3	5	7	10	2	27	8
	NO	39	55	65	124	22	305	92
Fertilizer Used?	DAP	15	24	27	46	9	121	36
	N.P.K (23:23:0)	12	17	23	27	7	86	26
	N.P.K (17:17:17)	9	12	10	19	4	54	16
	CAN	4	5	5	30	3	47	14
	Farm Yard Manure	2	2	7	12	1	24	7
	Others (unspecified)	0.6	0.4	0.2	1.8	0	3	1

Key: DAP=Di-ammonium Phosphate, N.P.K=Nitrogen, Phosphorous & Potassium; CAN=Calcium Ammonium Nitrate.

Findings indicated that, majority (62%) of the participating farmers were largely subsistence farmers, carrying out farming for food, while 30% did farming largely for income, implying the need to encourage more farmers to engage in farming business and the remaining 8% doing farming for other reasons. Farm funding is an important entry in farming activities, findings indicate that 76% of farm funding was done by individual farmers (self-financing), while 18% got funding support from the County Government of Laikipia, and the rest 6% received funding from other unspecified sources.

Majority (92%) of farmers relied on rain-fed farming, while 8% of the them used supplemental irrigation where, out of these 5% representing majority, were from Tigithi and Ngobit wards which could be attributed to the large areas which are ecologically dry in these sites and where according to Ngigi *et al.,* (2005). On extension services, 73% of the farmers preferred receiving information on new farming technologies from government extension service providers, 12% received agriculture extension information from private service providers and 15% obtained information for decision making on farming from other sources such as the media.

Findings showed that majority (93%) of farmers cultivated maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.), as the main subsistence crop in the study area, while the remaining 7% of farmers cultivated other unspecified crops in addition to maize and beans. This means that, at least every farmer studied grew maize and beans, thus making these crops the most preferred annual crops grown by farmers. Findings, showed that majority (92%) of the farming is rain-fed, with 8% carrying out supplemental irrigation. It is common to find that, most farmers in lowland rain-fed agriculture in Laikipia County relying on supplemented irrigation especially in conventional farming (Sébastien *et al*., 2019).

Water shortage is a major problem for crop production worldwide, limiting the growth and productivity of many crops, especially in rain-fed agriculture (Govaerts, 2007; Kenya Seed Co., 2010).

Concerning fertilizer use by farmers, 36%, 25% and 15% of farmers used Di-ammonium Phosphate, N.P.K 23:23:0 and N.P.K 17:17:17 basal fertilizers for planting respectively, where 14% of them used Calcium Ammonium Nitrate (CAN) as top-dress fertilizer. Those who applied manure (FYM) and other unspecified fertilizers in their farming consisted of 7% and 1% respectively. According to Gitari *et al.,* (2014), the number of farmers adopting the use of manure as an organic amendment is gaining popularity among farmers who keep domestic animals. Household demographic characteristics according to Christiansen *et al.*, (2011), are associated with decision-making in the adoption of farm-level technologies.

4.1.4 Availability of Tools and Implements For CA Farmers

The results in Table 12 portray the different ways in which farmers adopting CA in the study area acquire their farming tools and implements. In terms of availability of CA tools and implements, the findings indicate that the ownership of tools/implements by farmers practising CA was varied. The findings show that 4.3% of farmers imported jab planters, while 95.70% of them obtained jab planters fabricated by the local dealers. On the other tools and implements used in CA farming, 82.35% of farmers obtained soil rippers by importation, while only 17.65% of them obtained it locally. The findings on the farmers using the 2-wheeled tractors, show that all the 100% farmers imported the 2-whelled tractors and none was fabricated locally. Farmers acquiring shallow weeders (zam-wipes), only 1.86% imported them, while the rest (98.14%) were made locally.

Table 12. Tools and Implements used by farmers in the study area

	Imported		Locally Fabricated	
	Frequency	%	Frequency	%
Jab Planters (*n=93*)	4	4.30	89	95.70
Soil Rippers (*n*=17)	14	82.35	3	17.65
2-Wheeled Tractors (*n*=7)	7	100.00	0	0.00
Shallow Weeders (*n*=215)	4	1.86	211	98.14
Total	**29**		**303**	

The findings imply that, acquiring of soil rippers and the two-wheeled tractors in the study area remains a challenge for most of the CA farmers, since these tools/implements are imported from other areas, except for jab planters and shallow weeders which are basically fabricated locally.

These findings are in agreement with those by Kaumbutho and Kienzle, 2007; Kuria *et a*l, 2022), that reported a challenge in the availability of farm tools and implements for implementing conservation agriculture in Laikipia. This renders an opportunity for local fabricators and input supplies to invest in jab planters and shallow weeders. As far as tools and implements for implementing CF is concerned, the survey did not document any challenge. The general picture is that, tools used in CA or CF farming in the study area, are either available locally or imported.

4.1.5. Farmers Perception on Farming Systems

Figure 8, shows the results of the compelling reasons as to why farmers adopted different farming system practices.

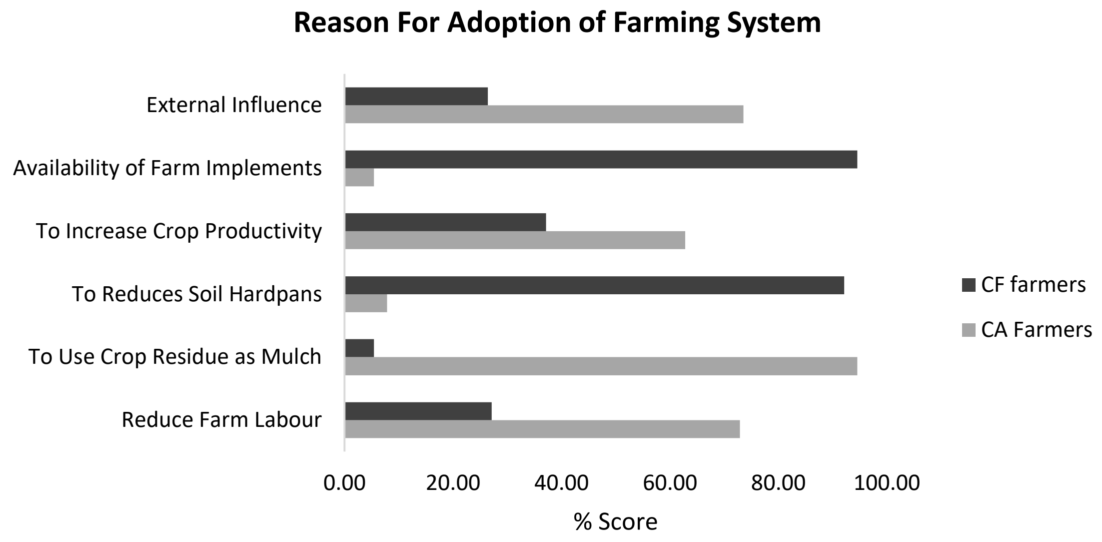

Figure 8. Farmers' Perceptions on Farming Systems and Practices

Concerning current farming systems, 4.07% of farmers reported that the adoption of their current farming was influenced by their peers. There were 15.36% of farmers who perceived that adoption of their current farming system was influenced by availability of farm tools and implements.

Farmers (20.49%) perceived that, their current farming system contributed to reduced soil degradation and improved soil condition. When it comes to farming and tillage practices, 11.15% of farmers perceived that their current farming system loosened soil aggregates making tillage and seeding easy to carry out. On crop residue utilization, 15.36% of farmers perceived that, crop residue should be fed to livestock. In terms of labor inputs, 30.58% of farmers perceived that their current farming systems required low inputs, while only 3.01% of farmers had other reasons for adopting their current farming system.

Research by Mucheru-Muna *et al*., (2021), found that farming systems had implications on labor and that tillage had effects on soil properties. Conservation agriculture can result in yield benefits in the long-term, and this may be up to 15 years with no yield benefits, which is in agreement with the findings of this study (Giller *et al*., 2011). Misiko and Tittonell, (2011) reported that farmers adapt and implement new technologies based on own understanding and interpretation, their own priorities and the possibilities to integrate new approaches into their farming systems. Competition between residues for mulch and use for livestock feed is the apparent contentious issue cited in most free-range livestock grazing systems (Guto *et al.*, 2011; Boudron *et al., 2*013). In some farms, the use of crop residues as livestock feed, burning of crop residues and uncontrolled grazing during the dry season means that maintaining a permanent crop cover in farms remains a challenge (Boudron *et al.*, 2015).

According to Valbuena *et al.*, (2012), crop residues has become a major source of livestock feed and especially during the dry season in dry land farming systems.

Evidence has shown that, smallholder farmers in low rainfall areas of Africa face major challenges in apportioning crop residues for livestock feed on one hand and their use for mulching in conservation agriculture on the other hand (Baudron *et al*., 2013). Adoption of CA farming system must therefore be able to address the livestock need for feed supply, while still sustaining adequate crop biomass on the soil. One of the suggested solutions to this challenge and which can ensure sustainable supply of livestock feed is to introduce forage crop in rotation or interaction with the main crop (Valbuena *et al.*, 2012; 2011; Baudron *et al*., 2013).

The findings indicated that adoption, suitability and practice of particular farming system depended on farmers preferences and individual judgments. This demonstrates that there were significant differences in adoption and practice of different farming systems among farmers in the study area, contrary to the null hypothesis that there are no significant differences in farming systems. According to Okeyo, (2016), adopters of technology play an important role in continuing and modification of technologies, and therefore their experiences should be incorporated in development of interventions. This principle applies to farmers as well in the adoption and adaptation of farming technologies. Ashraf *et al.,* (2015), associated farmers' age and education level with farm decision making.

The government according to the findings remains the main provider of agricultural extension services and financing, hence plays a key role in providing information and resources for decision making. This input is critical in supporting agricultural development in line with the Comprehensive African Agricultural Development Plan (CAADP) requiring allocation of at least 10% of public resources to agriculture (FAO, 2010).

As way to improve adoption of technologies, innovations and management practices (TIMP) in climate smart agriculture among farmers, local fabrication of CA tools and implements is required where such tools/implements do not originate locally. As far as adoption of CA is concerned, trade-off should be provided in CA to ensure a balance between utilizing crop residues for farming or as animal feeds as a way to minimize competition for crop residues between farming and livestock (Boudron *et al*., 2015; Guto *et al*., 2011).

4.2 Variation of Soil Properties under Conservation Agriculture

In this section, the results of soil analysis for selected soil properties in farms adopting conservation agriculture, with conventional farming systems and reference land being used as the control, are presented.

4.2.1 Variations in Soil Texture in the Sampled Farms

The proportion of sand, clay and silt separates in soils between 2 mm and 0.2 mm in diameter were classified as sand particles, those between 0.2 and 0.02 mm in diameter were classified as silt and those less than 0.02 mm in diameter classified to as clay (USDA, 2017).

The results showing the textural classes of soils found in the study area are shown in Table 13.

Table 13**.** Soil textural classes of surveyed farms

	Sandy Clay (SC)	**Silty Clay Loam (SCL)**	**Sandy Loam (SL)**	**Total farms**
Mukogodo (n=3)	0	3	0	3
Umande (n=5)	3	2	0	5
Tigithi (n=12)	0	9	3	12
Ngobit (n=7)	6	2	0	8
Thingithu (n=2)	0	2	0	2
Frequency	*9*	*18*	*3*	*30*
Percentage	*30*	*60*	*10*	*100*

KEY: n = represents the number of farms sampled in each ward

The results of soil classification based on major soil types in the studied farms showed three major soil textures; silt clay loam (SCL), silt clay (SC) and sandy loam (SL). The soil separate with the highest composition was SCL at 60%, followed by SC at 30% and SL at 10%. This implies that, the major soil textural class in the study area is the silt clay loam soil type, with much of this soil type being found in Tigithi ward.

4.2.2. Variability in % Mean Soil Moisture at 25 Days Intervals after Seeding

The daily %mean soil moisture content for six months from the first day to the last day of the month was recorded.

The mean soil moisture at the first 25 days after seeding ('DAS') were significantly higher under CF than under CA in all the five sites. Except in Tigithi, the %mean soil moisture levels declined as we moved from 25 "DAS" to 75 "DAS" in all the other sites. This is thought to be the result of diminishing rainfall both in amount and intensity, towards the end of the rainy season.

The %mean volumetric soil moisture after every 25 days after seeding ('DAS') intervals was calculated and the results analyzed and presented using bar graphs as shown in figure 9.

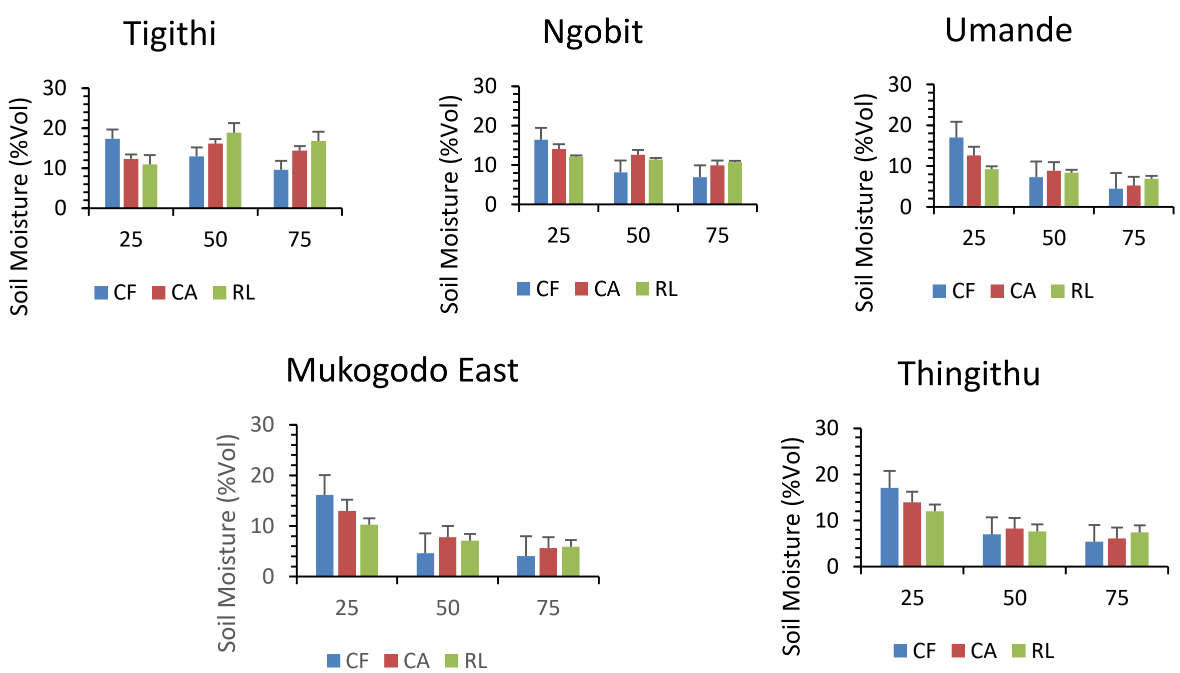

Figure 9. Bar charts representing %mean volumetric moisture at 25 after seeding (DAS) intervals under CA and CF farming systems. Mean error bars in the same cluster that do not overlap are significantly different ($p < 0.05$).

Results demonstrated that, the mean percentage in soil moisture at Tigithi ward was significantly higher at all stages (25, 50 and 75) 'DAS' under CF and CA farming systems. Further probing of the history of this particular site indicated that farmers are being involved in supplemental irrigation for horticultural farming during the dry season in compared to the other sites. These findings are in agreement with findings by Ngigi *et al.,* (2005), who reported the use of supplemental irrigation by farmers in Tigithi and some parts of Ngobit wards, in Laikipia.

Huho *et al.,* (2012) and Sébastien *et al*., (2019), showed that, more rain water is held in conventional farming at the inception of rain season. In other studies, Falkenmark *et al.*, (2019) demonstrated that, uncultivated land absorbs soil moisture more slowly, with greater potential of retaining the moisture in subsequent days due to the presence of decomposing crop residues that facilitate infiltration and retention of water into the soil when it rains or irrigation is done. He argued that CF as compared to CA can retain more soil moisture at the start of the season, since one of the most important farm operations in CF is ground opening during ploughing at the start of a rainy season. This subsequently leads to water penetrating to the soils with ease and absorb more water when it rains, but loses that moisture faster than CA when the temperature rises. Gomez *et al*., (2009) findings were however dissenting and did not establish any differences in infiltration rates between conventionally managed soils and those under conservation agriculture farming.

In instances where soil moisture fell below 12% in as early as 25 'DAS' in farming systems, it is recommended that farmers practice dry planting in order to utilize rain water, since moisture is scarce in the study area and rainfall is low (Sébastien *et al*., (2019) and unable to sustain the crop from planting to maturity.

The use of supplemental irrigation (SI) (green water) is necessary in the study area. These findings are also in consistent with findings by Teame, *et al.*, (2017) on the use of supplemental irrigation during dry season by farmers in Laikipia. Furthermore, Ngigi, *et al* (2005) showed that supplementary irrigation (SI) to crops is required in rain-fed farming in dry land farming since soil moisture is in deficit and is unable to sustain crop farming during the critical growing period between crop planting and crop physiological maturity without supplementary irrigation.

4.2.3 Variation in Soil Bulk Density under Farming Systems

The findings on the analysis of soil bulk density in soil samples from farming systems in the study areas are shown in table 14. Soil bulk density (BD) *(g/cm^3)* differed between different farming systems and the reference land as shown in table12.

Table 14. Analysis of Variance in Soil Bulk Density (g/cm3) In the Studied Farms

Farm no.	Farming system	Tigithi (n = 12)			Ngobit (n = 7)			Umande (n = 5)			Mukogodo East (n = 4)			Thingithu (n = 2		
		Mean	SE	pr>F	Mean	SE	pr>F	Mean	SE	pr>F	Mean	SE	pr>F	Mean	SE	pr>F
1	CA	1.23a	0.04	0.102	1.36b	0.06	0.047	1.76b	0.04	0.054	1.78b	0.04	0.054	1.21a	0.07	0.059
	CF	1.04a	0.05		1.14a	0.02		1.04a	0.03		1.01a	0.03		1.30a	0.06	
	RL	1.28a	0.06		1.28b	0.05		1.44b	0.2		1.54b	0.2		1.29a	0.06	
2	CA	1.32a	0.05	0.443	1.50a	0.02	0.111	1.22a	0.09	0.189	1.02a	0.0	0.189	1.32a	0.06	0.0*
	CF	1.35a	0.05		1.14a	0.06		1.06a	0.0		1.06a	0.02		1.09b	0.01	
	RL	1.43a	0.02		1.35a	0.10		1.82a	0.02		1.22a	0.09		1.43a	0.02	
3	CA	1.31a	0.02	0.054	1.56a	0.01	0.00*	1.38a	0.05	0.064	1.38ab	0.05	0.01*			
	CF	1.17b	0.04		1.11b	0.01		1.15a	0.06		1.15a	0.06				
	RL	1.35a	0.02		1.37c	0.05		1.57b	0.03		1.57b	0.03				
4	CA	1.34b	0.06	0.03*	1.32a	0.07	0.054	1.19a	0.05	0.058	1.29b	0.05	0.054			
	CF	1.13a	0.04		1.13a	0.01		1.07a	0.03		1.07a	0.03				
	RL	1.33b	0.06		1.42b	0.04		1.32b	0.04		1.32b	0.04				
5	CA	1.23a	0.04	0.053	1.24a	0.05	0.579	1.24a	0.04	0.617						
	CF	1.25b	0.05		1.15a	0.02		1.07a	0.13							
	RP	1.33b	0.01		1.20a	0.05		1.13a	0.04							
6	CA	1.25a	0.08	0.231	1.10a	0.03	0.04									
	CF	1.11a	0.02		0.99a	0.03										
	RL	1.31a	0.03		1.22b	0.09										
7	CA	1.40b	0.04	0.02*	1.25a	0.01	0.00*									
	CF	1.13a	0.06		1.13a	0.01										
	RL	1.53b	0.06		1.34b	0.09										
8	CA	1.31a	0.03	0.182												
	CF	1.11a	0.01													
	RL	1.37a	0.03													
9	CA	1.26a	0.02	0.00*												
	CF	1.11a	0.01													
	RL	1.36b	0.04													
10	CA	1.28a	0.01	0.189												
	CF	1.15a	0.05													
	RL	1.37b	0.04													
11	CA	1.38a	0.05	0.01												
	CF	1.15a	0.06													
	RL	1.57b	0.03													
12	CA	1.02a	0	0.189												
	CF	1.06a	0.02													
	RL	1.22a	0.09													

In Umande ward, soil bulk density (BD) had a mean value of 1.319732 gcm^{-3} in 2019 and 1.229384 gcm^{-3} in 2020 in farms adopting conservation agriculture (CA), while farms adopting conventional farming (CF) had a mean value of 1.072879 gcm^{-3} in 2019 and 1.066582 gcm^{-3} in 2020, that of the reference land was 1.309605 gcm^{-3} in 2019 and 1.240594 gcm^{-3} in 2020. The findings showed that, farms adopting CA in Mukogodo East had mean BD values of 1.24 gcm^{-3} and 1.42 gcm^{-3} in 2019 and 2020 respectively; those adopting CF had mean BD values of 1.141932 gcm^{-3} and 1.104565 gcm^{-3} in 2019 and 2020 respectively, while samples from the reference land had mean BD values of 1.252654 gcm^{-3} and 1.432272 gcm^{-3} in 2019 and 2020 respectively. In Ngobit ward, the findings of soil BD showed that, farms adopting CA had a mean BD of 1.314039 gcm^{-3} and 1.268768 gcm^{-3} in 2019 and 2020 respectively, those adopting CF had mean BD of 1.108026 gcm^{-3} and 1.107032 gcm^{-3} in 2019 and 2020 respectively, while findings from samples collected from the RL had mean BD of 1.308899 gcm^{-3} and 1.232442 gcm^{-3} in 2019 and 2020 respectively.

In Tigithi ward, the findings of soil BD showed that, farms adopting CA had a mean BD of 1.270152 gcm^{-3} and 1.311872 gcm^{-3} in 2019 and 2020 respectively, those adopting CF had mean BD of 1.149717 gcm^{-3} and 1.121812 gcm^{-3} in 2019 and 2020 respectively, while findings from samples collected from the RL had mean BD of 1.318625 gcm^{-3} and 1.371408 gcm^{-3} in 2019 and 2020 respectively. Findings of soil BD in farms adopting CA in Thingithu had mean values of 1.277282 gcm^{-3} and 1.298514 gcm^{-3} in 2019 and 2020 respectively, those adopting CF had mean BD of 1.071125 gcm^{-3} and 1.149469 gcm^{-3} in 2019 and 2020 respectively, while soils from the RL had mean BD values of 1.356263 gcm^{-3} and 1.366454 gcm^{-3} in 2019 and 2020 respectively.

These findings are consistent with findings by Tripathi *et al*., (2007) and Mohammadi *et al.,* (2009), that showed varying effects of farming on soil bulk density under conventional and conservation farming systems.

Overall, findings show that farms adopting CA and those from the reference land had significantly ($p < 0.05$) higher soil BD values than those adopting CF in most cases evaluated in this study. Tanveera *et al*., (2016), has recommended an optimal soil bulk density of between 1.2 gcm^3 and 1.6 gcm^3 as this will allow maximum soil porosity, root penetration, moisture absorption and nutrient availability. The BD levels in most of the farms adopting CF, were well within the optimal BD range recommended in farming systems.

Studies by Verhulst, (2010), demonstrated that, long term non-tillage farming systems affected soil BD by making soils to compact and develop soil hard pans, since most of the soils relied more on 'biological' tillage rather than 'physical' tillage'. Although studies by Kamiri *et al*., (2022), indicated increase in organic biomass on soil surface led to increased SOC and low soil BD, the study only evaluated the distribution of soil properties across an open-grazed pastoral system, and not the practices employed in CA farming, particularly the nil/reduced tillage that tends to compact surface soil. However, timely soil ripping can overcome compaction of soil aggregates in farms adopting CA (FAO, 2019).

4.2.4 Variation in Soil pH $_{(H20)}$ *Under Farming Systems*

Soil analysis to determine soil pH in samples obtained from farms adopting CA, CF and the reference land are shown in table 15. Soil pH didn't differ among farming systems in all the five wards.

Table 15. Mean Values of Soil pH in farms

		Farm1	Farm2	Farm3	Farm4	Farm5	Farm6	Farm7	Farm8	Farm9	Farm10	Farm11	Farm12	*Mean*
Tigithi	RL	5.27	5.19	7.41	5.78	7.31	8.18	6.39	6.03	6.3	5.98	6.22	6.29	6.363
	CA	5.38	5.58	6.07	8.32	8.14	6	5.9	6.83	5.69	6.27	5.6	5.96	6.312
	CF	4.99	5.99	5.66	4.31	7.11	5.77	5.5	4.65	5.45	5.86	5.32	5.95	5.547
Ngobit (*n=8*)	RL	5.96	7.4	7.34	5.99	6.2	5.95	6.32	8.12					6.660
	CA	8.37	6.08	7.11	6.06	7.3	6.59	5.67	5.74					6.615
	CF	4.34	5.67	5.64	5.67	5.71	5.39	5.48	4.33					5.279
Umande (*n=5*)	RL	7.07	6.03	6.66	6.30	6.27								6.466
	CA	6.18	5.84	6.89	5.69	5.98								6.116
	CF	4.74	5.95	5.31	5.45	5.86								5.462
Mukogodo E (*n=3*)	RL	8.89	6.24	5.60										6.910
	CA	6.03	5.72	6.42										6.057
	CF	4.21	6.01	5.65b										5.110
Thingithu (*n=2*)	RL	6.92	6.43											6.675
	CA	6.11	6.83											6.470
	CF	5.64	5.83											5.735

Findings on the adoption of farming practices by farmers outlined earlier in this study, showed that diammonium phosphate [$(NH_4)_2HPO_4$] fertilizer, is used by most farmers in the study area. Diammonium phosphate (DAP), generates two H^+ ions for each ammonium molecule nitrified to nitrate, which can acidify soil (CropNutrition, 2016; FTRC, 2013). Replacing DAP with as alternative fertilizers such as N.P.K, 23:23:0 or 17:17:17 available at most local agro-dealers in the study area, can reduce release of H^+ thus lowering soil pH. Results of soil analysis show that the mean soil pH in Tigithi ward, was 6.363 in soils from the reference land, 6.312 in farms adopting CA and 5.547 in farms adopting CF. In Ngobit ward soil pH was 6.15 in farms adopting CA, 5.279 in farms adopting CF and 6.660 in soils obtained from RL. In Umande ward, soil pH was 5.462 in farms adopting CF farming, 6.116 in farms adopting CA and 6.466 in the reference land. In Mukogodo East ward, soil pH was 5.110 in farms adopting CF, 6.910 in reference land and 6.057 in farms adopting CA. The results of soil pH analysis from Thingithu ward indicate that soil pH was 5.735 in farms adopting CF, 6.470 in farms adopting CA and 6.675 in the reference land.

In all the 30 farms studied, the findings of the mean soil pH ranged from 5.1 to 6.9, which can be considered to be slightly acidic. According to Kissel *et al*, (2012), soil pH values <7 are classified as acidic, while those >7 are classified as alkaline. The optimum soil pH levels in agricultural soils for most crops, range between 6.5 (slight acidic) to 7.5 (slightly alkaline) (Kissel *et al*, 2012; Tanveera *et al*., 2016).

Comparatively, soil pH was significantly higher in most soil samples obtained from the reference land when compared to those from the CA and CF, but significantly lower in CF farming system, than both in CA and the RL.

These findings have the implication that, farming systems that promote increased biomass retention of the soil can contribute to increased soil organic matter, capable of buffering soil pH (Butterly *et al*., 2011). It is noted that the increased soil organic matter makes H+ to contend with other cations for transaction sites and consent more base cations on the particle transaction sites, which tend to contribute to alkaline soils (Gruba and Mulder, 2015; Butterly *et al.*, 2011). According to Gruba and Mulder (2015), increase in soil organic matter and change in land management practices can also contribute to buffering of soil pH. The consistently low soil pH in most of the conventional farming systems can result to soil aluminium and manganese toxicity and fixation of some of the soil nutrients leading to inefficient nutrient uptake and slow crop root development and lower produce (Maskina *et al*., 1993). Studies indicate that the optimal growing pH levels for most annual crops cultivated in the study area, including; maize, wheat, beans, peas, potatoes, cabbages and tomatoes, ranges between; 5.4 to 7.0, and the findings were generally within the recommended ranges for most of the crops (Mutuku *et a*l., 2015). According to Butterly *et al*., (1), soil pH can also be influenced pH by long-term use of ammonia based fertilizers in farming. Ammonia (NH_4^+) oxidation to nitrite (NO^{2-}) and nitrate (NO_3^-) produce hydrogen ions (H^+) that acidify soil and can lower soil pH (CropNutrition, 2016). The use of DAP fertilizer as the preferred basal fertilizer by most farmers in the study area could acidify soils and lower soil pH (FTRC, 2013). In addition, soil tillage and decomposition of raw crop residues in soils can also lead to increase in H^+ hence create temporal low soil pH within the plough layer due to leaching of base cations, according to Verhulst (2010). In addition, farmers have the option of using soil amendments such as agricultural lime if their soil pH fell below pH of 5.

4.2.5 Variations in Total Soil Nitrogen (%)

The results of soil analysis, indicating variations in percentage total soil nitrogen from farms adopting CA, CF and the reference land are shown in table 16.

Table 16**.** Mean Soil Nitrogen under Different Farming Systems in Five Sites

		FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11	FM12	Mean	Rating
Tigithi(n=12)	RL	0.410	0.200	0.150	0.160	0.040	0.920	0.260	0.520	0.480	0.520	0.760	0.820	0.437	high
	CA	0.260	0.180	0.140	0.430	0.170	0.460	0.170	0.420	0.410	0.390	0.540	0.450	0.335	high
	CF	0.130	0.150	0.380	0.140	1.920	0.290	0.140	0.250	0.300	0.400	0.240	0.290	0.386	high
Ngobit(n=7)	RL	0.160	0.630	0.370	0.440	1.190	0.560	0.810						0.594	high
	CA	0.150	0.250	1.910	0.280	0.190	0.350	0.310						0.491	high
	CF	0.140	0.110	0.150	0.230	0.140	0.140	0.130						0.149	low
Umande(n=5)	RL	0.310	0.250	0.180	0.920	0.290								0.390	high
	CA	0.320	0.410	0.410	0.430	0.360								0.386	high
	CF	0.260	0.490	0.140	0.180	0.142								0.242	moderate
MukogodoE(n=4)	RL	0.220	0.170	0.230	1.260									0.470	high
	CA	0.190	0.180	0.410	0.150									0.233	moderate
	CF	0.220	0.210	0.130	0.250									0.203	moderate
Thingithu(n=2)	RL	0.160	0.480											0.320	moderate
	CA	0.130	0.143											0.137	low
	CF	0.140	0.210											0.175	low

Nitrogen N (%) Rating: *>0.25 high, 0.12-0.25 moderate, 0.05-0.12 low, <0.05 very low. (Tekalign, 1991).*

Studies by Tekalign, (1991) on general guidelines on the interpretation of soil N test values indicate that, % N levels in soils may be considered high if >0.25. Results show that the mean levels of total soil Nitrogen between farming systems in Tigithi ward were 0.386% in farms adopting CF, 1.335% in farms adopting CA and 0.437% in reference land. The %N in this site was rated as high in across all the farming systems. In Ngobit ward, % total soil nitrogen were 0.149% in farms adopting CF, 1.491% in farms adopting CA and 0.594% in reference land, with a rating of high in both CA and RL, but low in farms adopting CF. In Umande ward, the % mean soil nitrogen were 0.386% in farms adopting CA, 0.242% in farms adopting CF and 0.390% in the reference land, and were rated as high in both CA and reference land, but moderate in farms adopting CF. In Mukogodo east, the % mean nitrogen were levels were 0.470% in the RL, 0.233% in farms adopting CA and 0.203% in farms adopting CF, and were rated as high in RL and moderate in both CA and CF. In Thingithu ward, the % mean nitrogen were levels were 0.320% in the RL, 0.137% in farms adopting CA and 0.175% in farms adopting CF, and were rated as moderate in RL and low in both CA and CF.

According to Tekalign, (1991), a good level of nitrogen in the soil is between 0.3-0.4 percent. However, findings in this and other studies by Alavaisha *et al.,* (2019), concluded that, the availability and uptake of nitrogen from the soil is a very complex process and cannot be affected by farming systems alone, but is affected by many other parameters, such as soil moisture levels, microbial activity, soil aeration, EC, pH and soil structure. Overall, findings showed that the percentage soil nitrogen levels from the studied farms were largely moderate in most of the farms studied.

4.2.6 Variation in Total Soil Organic Carbon

The results of soil analysis, indicating variations in percentage total soil organic carbon from farms adopting CA, CF and the reference land are shown in table 17. In this study, findings of mean percentage soil organic carbon (%SOC) in farms adopting CA in Tigithi ward, ranged between 9.814 in reference land, 6.953 in farms adopting CA and 3.565% in farms adopting CF. The %SOC levels differed significantly across farming systems and the reference land and were rated as high in all practices. In Ngobit ward, %SOC were 2.726 in farms adopting CF, 8.219 in farms adopting CA and 12.439 in the RL. The levels were significantly different across practices and were rated as high in the reference and CA and moderate in CF.

The levels of %SOC under CA, CF and the RL in Umande ward, were 2.366% in farms adopting CF, 5.128% in farms adopting CA and 6.688 in the RL. The levels were significantly different between CF and CA and CF and RL, but did not differ significantly between CA and the RL, and were rated as high in the reference and moderate in both CA and CF. In Mukogodo East ward, the mean %SOC were 1.850% in farms adopting CF, 3.180% in farms adopting CA and 5.438% in the RL. The levels were significantly different across practices and were rated as high in the reference and CA and moderate in CF. In Thingithu ward, %SOC in farms adopting CF were 1.765% and rated as low, 3.160% in CA and rated as moderate, and 7.815% in RL and rated as high. Percentage organic carbon differed significantly across farming systems and the reference land.

Table 17. Mean Soil Organic Carbon (%) Under Different Farming Systems In the Five Sites

		FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11	FM12	%Mean	*Rating*	*group*
Tigithi (*n=12*)	RL	12.44	13.75	9.13	10.87	10.6	13.43	10.46	10.79	11.83	5.92	3.93	4.62	9.814	High	*a*
	CA	9.68	9.16	6.11	8.09	9.87	10.45	6.22	6.01	8.14	4.51	2.61	2.58	6.953	high	*b*
	CF	3.32	4.66	4.25	5.59	3.6	2.36	3.55	4.99	3.55	2.43	1.96	2.52	3.565	high	*c*
Ngobit (*n=7*)	RL	12.51	10.12	12.33	14.58	11.83	15.94	9.76						12.439	high	*a*
	CA	7.53	6.23	9.02	8.03	9.74	10.17	6.81						8.219	moderate	*b*
	CF	1.41	2.56	2.29	4.46	1.33	4.96	2.07						2.726	moderate	*c*
Umande (*n=5*)	RL	6.92	8.97	4.61	7.75	5.19								6.688	high	*a*
	CA	4.21	5.44	6.21	5.82	3.96								5.128	moderate	*a*
	CF	1.56	2.04	3.05	2.09	3.09								2.366	moderate	*b*
Mukogodo E (*n=4*)	RL	6.43	4.58	3.81	6.93									5.438	high	*a*
	CA	2.81	2.32	3.08	4.51									3.180	high	*b*
	CF	2.03	1.83	1.02	2.52									1.850	moderate	*c*
Thingithu (*n=2*)	RL	9.92	5.71											7.815	high	*a*
	CA	4.15	2.17											3.160	moderate	*b*
	CF	1.65	1.88											1.765	low	*c*

Carbon C (%) Rating: >3 high, 1.5-3 moderate, 0.5-1.5 low, <0.5 very low; (Tekalign , 1991).

Studies on general guidelines on the interpretation of soil C test values indicate that, % SOC levels of >3% are considered high, 1.5-3.0% are considered to be moderate, 0.5-1.5% are considered to be low, while below 0.5% are considered to be very low (Tekalign, 1991).

Overall results showed that, the %total organic carbon in soils ranged from high to moderate in most of the farms adopting CA and the reference land, while the levels in farms adopting CF ranged from marginally low to moderate. The study concludes that, farms adopting CA farming system had higher levels of SOC when comparable to those adopting CF, which agrees with findings by (Chai *et al*., 2015; Wang *et al*, 2013). This study postulated that; the high use of organic biomass from crop residues and other organic crop cover on the soil increased soil organic carbon levels in CA and the reference. Cooper *et al*., 2014, demonstrated that soil organic carbon levels are higher in some farming systems where crop residues are in-cooperated into the soil, than in those where land tillage activities expose soils to enormous oxidation. Studies have demonstrated increase in soil organic carbon in farming systems (Sharma *et al*., 2016), with demonstrated evidence in sequestration of soil carbon in the soil when farmers change from CF to CA farming system.

Conservation farming systems have been associated with increased soil organic carbon (SOC) which is a significant cornerstone for improving the overall greenhouse gas balance of agricultural sector by enhancing the potential for soil C sequestration in organically managed soils as compared to conventional farming (Chai *et al*., 2015). Soil organic carbon (SOC) is a major indicator of soil fertility in farming systems and is firmly connected to soil productivity and its deficiency is linked to decline in soil fertility, soil nutrient supply and availability of soil nitrogen (N), according to Wang et al., (2013).

The use of crop residues in CA farming according to Kirkby *et al.*, (2013), leads to increased soil organic matter, cycling of major plant nutrients and serve as both a source and sink of soil organic carbon, explaining the possible reason why soil organic carbon and nitrogen in particular were significantly higher in CA and the the reference. Further, Gitari *et al,* 2014, reported that farmers in Tigithi and Ngobit sites which had higher level of SOC had histories of adopting good farming management practices and some of them made use of farm yard manure (FYM) from their livestock yards, which is postulated to have contributed to these findings.

In other studies, Cooper *et al*., 2014, has demonstrated that soil organic carbon levels are higher in farming systems where crop residues are in-cooperated into the soil, than in those where land tillage activities and non-retention of crop residue, leading to soil exposure to enormous oxidation processes (Murphy, 2015). Increased soil organic matter from retention of crop residues in CA, contribute to higher CEC, cycling of plant nutrients and serve as both a source and sink of soil organic carbon (Sharma *et al*., 2016), explaining the possible reason why soil organic carbon was particularly significant in CA and the reference land. The study also established that, some farmers applied farm yard manure in their farms (Gitari *et al*., 2014).

4.2.7 Soil Carbon to Nitrogen Ratio Rating

Soil carbon to nitrogen ratio (C:N) is defined as a measure of the mass of carbon to the mass of nitrogen in the soil (USDA, 2017).

The results of soil analysis, comparing the levels of %soil nitrogen and %soil organic carbon ratios from farms adopting CA and CF are shown in table 18.

Table 18**.** Soil Carbon to Nitrogen Ratios and Ratings In Soil Samples

Site		Tot SOC(%)		Tot N(%)		
		Mean	Rating	Mean	Rating	C:N
Tigithi (n=12)	RL	5.81	high*	0.237	high	24.53
	CA	4.95	high	0.235	high	21.08
	CF	3.57	high	0.261	high	9.828
Ngobit (n=7)	RL	5.44	high*	0.294	high	18.5
	CA	2.52	moderate	0.291	high	8.656
	CF	1.43	low	0.149	moderate	9.57
Umande (n=5)	RL	3.69	high	0.189	moderate	19.51
	CA	2.13	moderate	0.286	high	7.441
	CF	0.37	very low	0.242	moderate	1.512
Mukogodo(n=4)	VL	2.44	moderate	0.227	moderate	10.74
	CA	2.12	moderate	0.233	moderate	9.09
	CF	1.84	low	0.203	moderate	9.039
Thingithu (n=2)	RL	3.82	high	0.322	moderate	11.85
	CA	3.12	high	0.157	moderate	19.85
	CF	1.77	moderate	0.175	moderate	10.09

Rating: Carbon C(%) >3 high, 1.5-3 moderate, 0.5-1.5 low, <0.5 very low; Nitrogen N(%) >0.25 high, 0.12-0.25 moderate, 0.05-0.12 low, <0.05 very low. (Tekalign , 1991):

The results of the analysis of soil organic carbon to nitrogen ratio (C:N) in Tigithi ward were; 22:1, in the reference land, 21:1 in farms adopting CA and 14:1 for the farms adopting CF. In Ngobit ward, soil carbon to nitrogen ratio measured 21:1 in the reference land, 17:1 in farms adopting CA and 18:1 in farms adopting CF. Findings of C:N from indicate that, farms Umande ward indicated that 17:1 in the reference land, 13:1 in farms adopting CA and 10:1 in farms adopting CF. Farms adopting CA in Mukogodo East had soil carbon to nitrogen ratio of 14:1, those farms adopting CF had soil carbon to nitrogen ratio of 9:1, while the reference land 17:1 soil carbon to nitrogen ratio.

In Thingithu ward, farms adopting CF had soil carbon to nitrogen ratio of 10:1, those adopting CA farming had soil carbon to nitrogen ratio of 20:1, while the RL had soil carbon to nitrogen ratio of 24:1. According to Bhattacharyya and Jha, (2012), an optimum C:N ratio in the soil is about 15:1 to 20:1. Soil micro-organisms need a C:N ratio of 24:1 in order to grow and thrive, and a C:N ratio of 8:1 to exist. A low C:N ratio (<15) means that the microbes will consume the organic matter and leave any excess nitrogen in the soil (mineralization). A high C:N ratio (>25) means that the microbes take nitrogen out of the soil (immobilisation) so that it is temporarily unavailable to the plants. Overall, the findings of this study indicated that, soil carbon to nitrogen ratio (C:N) ratios in most of the farms in the study area was lower than the threshold of 24:1. This has the implication that, the optimal growth of soil microbial population is highly affected in these farms. The findings also indicate that, most of the farms adopting CF had a C:N ratio ranging from 9 to 18, which explains why most farms adopting CF had higher levels of nitrogen, arising from N mineralization. The study recommend increased use of crop residues rich in legumes and the use of FYM to supply additional N required by microbes and facilitate increased supply of soil organic carbon from decomposition of organic matter (Ayamba *et al.*, 2021).

Studies have also shown that soil nutrients are chemically bound to carbon (C) in organic compounds (Cleveland *et al.*, 2007). Adoption of 3 principals of CA is expected to maintain optimal balance of soil carbon to nitrogen ratio to nurture a healthy environment for microbial growth and nutrients supply in soils in the study area.

4.2.8 Variation In Available Phosphorous Under Different Farming Systems

The results of soil analysis, indicating variations in available phosphorous (PPM) from farms adopting CA, CF and the reference land are shown in table 19.

Results indicate that available soil phosphorous (ppm) in farms practising CA farming in Tigithi ward ranged between 9.33 and 90.73 ppm, with a mean value of 39.23 ppm. Phosphorous in farms adopting CF in Tigithi ranged between 12.49 to 97.0 ppm, with a mean value of 36.08 ppm, that in the reference land ranged between 10.82 to 56.0 ppm, with a mean value of 22.71 ppm. In Ngobit ward, available phosphorous under CA ranged between 12.31 to 81.3 ppm, with a mean value of 33.48 ppm, that in farms adopting CF ranged between 17.21 to 46.86 ppm, with a mean value of 37.01 ppm, while that in RL ranged between 14.02 to 55.3 ppm in reference land, with a mean value of 31.57 ppm. In Umande, soil P (ppm) values in farms adopting CA ranged between 9.33 to 75.3 ppm with a mean of 30.40 ppm, the value in farms adopting CF ranged between 8.33 and 104.6 ppm, with a mean value of 38.12 ppm, that from RL ranged between 10.01 and 90.6 ppm, with a mean value of 35.79 ppm.

Table 19**.** Variation of Available Phosphorous (PPM) Under Farming Systems in Five Wards

	FS	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11	FM12	Mean
Tigithi (n=12)	RL	21.87a	13.63a	15.3a	10.82a	33.80a	26.7a	21.0ab	24.33a	56a	11.0a	15.33a	19.6a	22.71
	CA	90.73b	12.56a	27b	12.81a	45.3b	61.3b	49.0a	34.3a	76.2b	9.33a	13a	25.3a	39.23
	CF	32.77a	12.49a	16.86a	13.74a	48.6b	97c	30.33b	38.3a	70.33b	18.33b	18.1a	23.6a	36.08
Ngobit (*n=8*)	RL	32.82a	51.33a	55.3a	14.02b	21.79a	34.3b	16.2a	26.81a					31.57
	CA	24.81a	27.03b	81.3b	12.31a	32.95b	33.04a	27.52a	28.84a					33.48
	CF	42.74a	46.86a	64.3a	17.21b	31.69b	30.33b	30.21a	32.72b					37.01
Umande (*n=5*)	RL	51.3b	90.6b	10.01a	16.02a	11a								35.79
	CA	24.6a	75.3a	15.16a	27.62b	9.33a								30.40
	CF	19a	104.6c	8.33a	40.33b	18.33a								38.12
Mukogodo E (*n=3*)	RL	48.2a	16.33a	19.56a										28.03
	CA	52.01a	22.33b	12.3a										28.88
	CF	62.6a	19.12b	11.33a										31.02
Thingithu (*n=2*)	RL	13.38a	51.3a											32.34
	CA	42.67a	34.3a											38.49
	CF	54.56a	72.6b											63.58

Different letters indicate significant differences in nutrients between farming systems. Treatments with the same letter are not significantly different based on LSD t-test for post-choc pairwise comparisons at 95% confidence level.

Available soil phosphorous in farms adopting CA in Mukogodo East ranged between 16.33 and 48.2 ppm in the reference land, with a mean value of 28.03 ppm, in farms adopting CF, phosphorous ranged between 11.33 to 62.6 ppm, with a mean value of 31.02 ppm, the values ranged between 16.33 to 48.2 ppm in RL, with a mean of . 28.03 ppm. Available soil phosphorous under CA in Thingithu ranged between 34.3 to 42.67 ppm, with a mean value of 38.49 ppm, farms adopting CF had values ranging ranged between 54.56 and 73.6 ppm, with a mean value of 63.58 ppm, while that in the reference land ranged between 13.38 and 51.3 ppm, with mean value of 32.34 ppm.

According to Morar *et al*., (2008) an ideal phosphorous level in the soil phosphorous is approximately 30-70 ppm. Phosphorous is essential structural plant nutrient for the transfer of energy, development of reproductive structures, crop maturity, root growth and Protein synthesis (Li, *et al*., 2021). Low pH binds with aluminum and iron while high pH, binds with calcium or magnesium becoming unavailable to the plants (Morar *et al*., (2008). Soil microbial population and availability of soil organic matter may influence P uptake in soils through mineralization. Although according to (Daniells, 2012), subsoiling commonly practised in CA can result to greater increase in root length, surface area, and volume than deep tillage practised in CF, which can affect P uptake by roots, the study did not establish a consistent effect of farming systems on soil phosphorous.

4.2.9 Variations in Exchangeable Cations under Different Farming Systems

The results of soil analysis, indicating variations in soil potassium (K), calcium (Cal) and magnesium (Mg) from farms adopting CA, CF and the reference land are shown in table 20.

Table 20. Variation of Exchangeable Cations under Different Farming Systems

		Calcium (Meq)			Potassium (Meq)			Magnesium (Meq)		
	FM	RL	CA	CF	RL	CA	CF	RL	CA	CF
Tigithi (*n=12*)	1	1.14a	1.53ab	0.95b	8.33a	22a	10.6a	2.21a	2.06a	1.66a
	2	1.18a	1.47a	1.55a	11.33a	16.33a	21.66a	2.8a	3.26a	3.8a
	3	15.71a	4.42b	2.37b	9.74a	1.68a	1.22b	7.53a	5.81a	4.80a
	4	1.18b	12.42a	1.04b	9.64a	22.35a	11.33a	2.42a	2.44a	1.72a
	5	6.73a	1.44a	7.06a	7.92b	26.33a	1.58b	4.07a	7.06a	4.32a
	6	23.5a	8.26b	5.46b	6.81a	1.03b	1.34b	6.19a	4.10b	3.32b
	7	13.8a	9.56a	5.73a	8.99a	1.59a	1.76a	2.83b	3.79a	2.54b
	8	4.33a	16.87a	13.6a	8.72a	0.75a	0.63a	2.80a	4.27a	4.06a
	9	12.2a	2.92b	2.2b	4.64a	18.92a	1.3a	3.36a	2.26ab	1.78b
	10	12.46a	6.73a	5.4a	7.72a	1.54a	1.44a	3.41a	2.97a	2.57a
	11	4.73a	2.33a	3.3a	6.97a	1.68b	1.74b	4.64a	3.01a	2.66a
	12	5.76a	5.2a	4.66a	5.46a	2.26a	2.23a	4.32b	5.38a	4.76ab
Mean		*8.561*	*6.098*	*4.443*	*8.023*	*9.705*	*5.738*	*3.883*	*3.868*	*3.163*
Ngobit (*n=7*)	1	1.18b	12.42a	1.01b	9.66a	22.3a	11.3a	2.2a	2.43a	1.73a
	2	17.36a	19.0a	12.0a	1.34a	0.97a	1.54a	7.67a	5.81a	4.80a
	3	6.73a	1.49a	7.06a	0.94a	27b	1.55b	4.07a	7.06a	4.32a
	4	2.83a	4.12a	3.09a	2.28a	1.61a	1.74a	4.76a	3.72a	3.76a
	5	1.73ab	1.78a	1.26a	49.33a	44a	28.6b	4.96a	4.26a	3.19a
	6	14.7a	4.53b	2.33b	1.73a	1.74a	1.25b	2.9a	2.50a	1.44b
	7	12.1a	2.93b	2.23b	1.62a	18.91a	1.34a	3.34a	2.24ab	1.63b
Mean		*8.09*	*6.604*	*4.14*	*9.557*	*16.647*	*6.76*	*4.252*	*4.003*	*2.981*
Umande (*n=5*)	1	14.6a	14.2a	15.1a	1.32a	0.92a	1.62a	5.63a	5.46a	5.01a
	2	6.26a	5.26a	5.6a	2.33a	2.13a	2.26a	4.26a	5.12b	5.01b
	3	1.53a	1.41a	1.8a	0.86a	6.23b	0.81a	2.40ab	2.22b	2.76a
	4	12.23a	2.92b	2.2b	1.64a	18.9a	1.3a	3.36a	2.26ab	1.72b
	5	12.46a	6.73a	5.4a	1.72a	1.54a	1.44a	3.41a	2.97a	2.57a
Mean		*9.416*	*6.104*	*6.04*	*1.574*	*5.944*	*1.486*	*3.812*	*3.606*	*3.414*
Mukogodo(*n=4*)	1	22.6a	7.53b	7.86b	2.23a	0.93b	1.28b	5.43a	3.89b	3.76b
	2	5.46a	4.26a	12.93a	2.18a	1.6a	3.60a	3.25a	3.48a	3.85a
	3	4.41a	2.13a	2.93a	3.64a	1.65a	1.47a	4.33a	2.95a	2.56a
	4	1.16b	12.42a	1.03b	9.54a	22.38a	11.13a	2.32a	2.42a	1.73a
Mean		*8.405*	*6.585*	*6.1875*	*4.3975*	*6.6475*	*4.375*	*3.8325*	*3.185*	*2.975*
Thingithu(*n=2*)	1	1.44b	8.38a	1.89b	20b	55a	25.6b	10.33a	2.45b	2.6b
	2	17.66a	24.6a	14.9a	0.72a	0.75a	0.63a	3.92a	5.06a	4.35a
Mean		*9.55*	*16.49*	*8.395*	*10.365*	*27.875*	*13.115*	*7.125*	*3.755*	*3.485*

Different letters indicate significant differences in nutrients between farming systems. Treatments with the same letter are not significantly different based on LSD t-test for post-choc pairwise comparisons at 95% confidence level.

Exchangeable cations levels differed across farms in Tigithi, Ngobit, Umande, Mukogodo E and Thingithu sites, with significant differences occurring in some farms.

Soil Calcium

Soil Calcium(Cal) levels, in farms adopting CA farming system in Tigithi and Ngobit wards ranged between 1.44 to 16.87 $_{Meq}$ and 1.49 to 19.0$_{Meq}$ respectively, that in farms adopting CF ranged between 0.95 to 13.6 $_{Meq}$, and 1.01 to 12.0 $_{Meq}$ respectively, while that in RL ranged between 1.14 to 23.05 $_{Meq}$ and 1.01 to 12.0 $_{Meq}$ respectively. The mean values for calcium in Tigithi and Ngobit wards ranged between 4.443 to 8.561 $_{Meq}$ and 4.14 to 8.09 $_{Meq}$ respectively. Soil Calcium levels, under CA farming in both Umande and Mukogodo East wards ranged between 1.41 to 14.6 $_{Meq}$, and 2.13 to 12.42 $_{Meq}$ respectively, that under CF ranged between 1.81 to 15.1 $_{Meq}$ and 1.03 to 12.93 $_{Meq}$ respectively, and 1.53 to 14.6 $_{Meq}$ and 1.16 to 22.6 $_{Meq}$ respectively, in RL . The mean values for calcium ranged between 6.04 to 9.416 $_{Meq}$, and 1.41 to 14.6 $_{Meq}$, respectively. Soil Calcium levels, under CA farming in Thingithu ward ranged between 8.38 to 14.6 $_{Meq}$, that under CF ranged between 1.89 to 14.9 $_{Meq}$ and in RL the values ranged from 1.44 to 17.6 $_{Meq}$.

Significant effects are associated with farming practices on soil phosphorus (P), calcium (Cal) and potassium (K) levels. Just like in the other exchangeable cations evaluated in this study, the findings indicated that calcium levels differed significantly under different farming systems in different sites. Overall, the findings show that calcium was consistently higher in the soil and that its levels in the soil might have been influenced by the use of crop residue in CA. According to Palm *et al.*, 2014, the adoption of CA has been shown to increase soil calcium. In other studies, it has been shown that retention of crop residue on the soil surface increased soil calcium and other exchangeable cations in the soil (Wawrzyńska and Sirko, 2014).

Soil Potassium

Soil Potassium (K) levels, in farms adopting CA farming system in Tigithi and Ngobit wards ranged between 0.75 to 26.33 $_{Meq}$ and 0.97 to 22.3 $_{Meq}$, respectively, farms adopting CF had potassium levels ranged between 0.63 to 21.66 $_{Meq}$, and 1.25 to 28.6 $_{Meq}$ respectively, while that in RL ranged between 4.64 to 11.33 $_{Meq}$ and 0.94 to 49.33 $_{Meq}$ respectively. The mean values for calcium in Tigithi and Ngobit wards ranged between 5.738 to 9.75 $_{Meq}$ and 6.76 to 16.647 $_{Meq}$ respectively.

Soil Potassium levels under CA farming in both Umande and Mukogodo East wards ranged between 0.92 to 18.9.6 $_{Meq}$, and 0.93 to 22.38 $_{Meq}$ respectively, that under CF ranged between 0.81 to 2.26 $_{Meq}$ and 1.28 to 11.13 $_{Meq}$ respectively, while in RL, the values ranged from 0.86 to 2.33 $_{Meq}$ and 2.18 to 9.546 $_{Meq}$ respectively. The mean values in these sites ranged between 1.486 to 5.945 $_{Meq}$., and 4.375 to 6.648 $_{Meq}$, respectively. Soil Potassium levels, under CA farming in Thingithu ward ranged between 0.75 to 55 $_{Meq}$, that under CF ranged between and 0.63 to 25.6 $_{Meq}$ while in RL it ranged between 0.7 to 20.6 $_{Meq}$. The mean values ranged between 10.365 to 27.875 $_{Meq.}$

Soil Magnesium

Soil Magnesium (Mg) levels, in farms adopting CA farming system in Tigithi and Ngobit wards ranged between 2.06 to 7.06 Meq and 2.04 to 7.06 Meq respectively, farms adopting CF had potassium levels ranged between 1.66 to 4.80 Meq, and 1.44 to 4.80 Meq respectively, while that in RL ranged between 2.21 to 7.53 Meq and 2.2 to 7.67 Meq respectively. The mean values for calcium in Tigithi and Ngobit wards ranged between 5.738 to 9.705 Meq and 6.76 to 16.647 Meq respectively.

Soil Magnesium levels under CA farming in Umande and Mukogodo East wards ranged between 2.22 to 5.46.6 $_{Meq}$, and 2.42 to 3.89 $_{Meq}$ respectively, that under CF ranged between 1.72 to 5.01 $_{Meq}$ and 1.73 t 3.85 $_{Meq}$ respectively, while in RL, the values ranged from 2.40 to 5.63 $_{Meq}$ and 2.30 to 5.436 $_{Meq}$ respectively. The mean values in these sites ranged between 3.414 to 3.812 $_{Meq}$., and 2.975 to 3.832 $_{Meq}$, respectively. Soil Magnesium levels, under CA farming in Thingithu ward ranged between 2.45 to 5.06 $_{Meq}$, that under CF ranged between and 2.60 to 4.35 $_{Meq}$ while in RL it ranged between 3.92 to 10.33 $_{Meq}$.

The mean values ranged between 3.485 to 7.125$_{Meq.}$ Adoption of conservation agriculture farming systems can improve soils' ability to increase and cycle nutrients at crop root depth (20 cm), (FTRC, 2013).

The study postulated that, disparities in soil exchangeable cations across farming systems could have arisen from adopting different farming practices and the use of different fertilizers. Application of fertilizers in farming is thought to replenished phosphorus and the exchangeable cations; Ca^{2+}, Mg^{2+} and K^{+} contents, which were found generally higher in some farms adopting either CA or CF as compared to the reference land, where farming and use of farm inputs is not usually done. Overall, the levels of exchangeable cations were low in most farms, postulated to be due to low level of nutrient replenishment from external sources. Other factors for these results are associated with the use of soil acidifying inputs among farmers contributing to immobilization of soil N (Gitari *et al*, 2014; Bhattacharyya and Jha, 2012). The adoption of climate smart agriculture technologies is also recommended for improving soil fertility and increasing productivity as was seen to improve nutrients in CA in this study and has also been emphasized in studies by McCarthy *et al.*,(2011).

4.3 Soil Microbial Diversity under Farming Systems

The study identified a diversity of fungi and bacteria populations that play essential roles in agriculture and whose presence in the soil is a good sign of soil health in farming systems. The strains in the genera Acidobacter, Azospirillium, Azotobacter, Bacillus, Burkholdria, Enterobacter, Erwinia, Flavobacterium, Rhizobium and Serrotia were highly significant in soils under CA and the reference land (Figure 12). The discovery of rhizospheric bacteria and fungi from the agricultural soils with significant levels in CA farming system provides a new insight of looking into effective ways to promote the growth of useful soil microbes that can contribute to soil fertility improvement in integrated crop nutrient management systems (Mo *et al*., 2016). Promoting adoption of CA farming system among farmers in the study area is likely to improve soil microbial populations, capable of supplementing nutrients supply and bridge the gaps in soil nutrients supply in farming systems (Glick, 2012).

Transition from CF to CA according to Maurer *et al*., (2014), can provide soil health benefits associated with crop resilience to biotic and abiotic stresses and ecological fitness in the lowland rain-fed farming areas of in Laikipia. Further studies are required to establish whether other terrestrial and soil factors played any role in contributing to differences in of soil microorganisms in the study area. Since large populations of the microorganisms were analyzed from soil samples in this study, further selection and presentation of those organisms of economic importance in agriculture was done. The study concentrated on microorganisms that play major role in nutrient solubilization and decomposition of organic matter (Glick, 2012).

4.3.1 Diversity of Soil Bacteria in Studied Farms

Results of bacteria population diversities from the analyzed soil samples are presented Figure 10. Results showed that soil bacteria population varied significantly under CA, as well as CF in most sites. In terms of community populations in the five sites, candidatus nitrososphaera was the highest under RL in Mukogodo East ward than in all the other sites.

The most dominant species by farming systems in farms adopting CA in Mukogodo East ward as shown in figure 9. *Actinomyces spp*. were 1,148, *Candidatus Nitrososphaera gargensis* (1700), were the most dominant species in farms adopting CA in Ngobit ward, *Acidobacterium spp (*2,100) were the most dominant species in farms adopting CA in Thingithu ward, *Pelobacter spp.*(249) were the most abundant bacteria in Tigithi ward, while *Geobacter spp*.(1,720) were the most abundant bacteria in Umande ward.

Other dominant species found in farms adopting both CA and CF included; *Candidatus nitrososphaera* found in in Mukogodo East, *Acidobacterium spp, burkholderia spp*.and xanthomonas spp., found in Ngobit ward, Acidobacterium *spp*., and *Bacillus spp*. found in Umande. *Candidatus nitrososphaera*, *Candidatus Nitrososphaera gargensis* and *Pelobacter spp*., found in Tigithi, while *acidobacterium spp*, *bacillus spp*., and *Nitrospira sp*., were found in Umande ward.

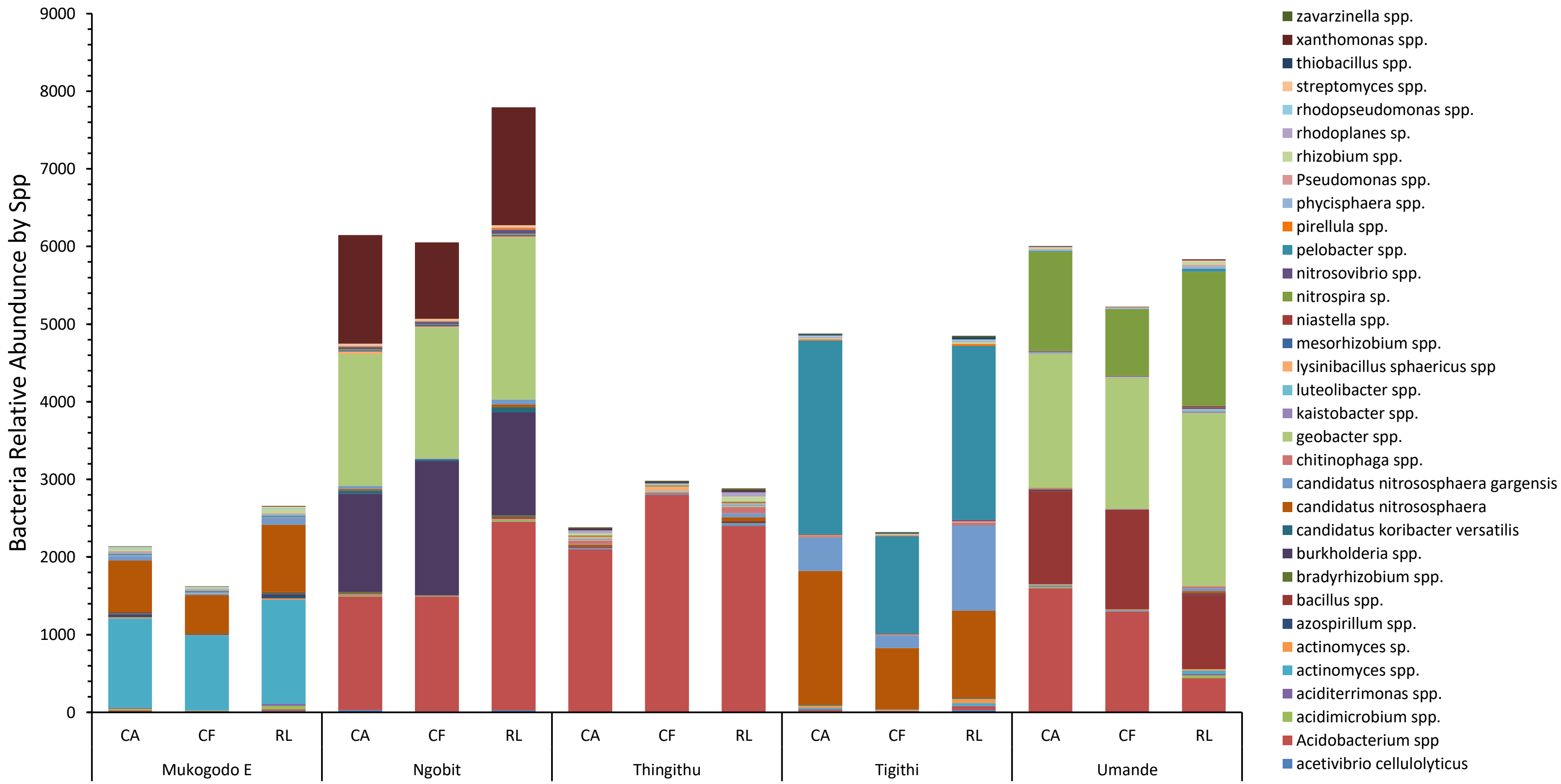

Figure 10. Relative microbial populations in soil under CA and CF farming. KEY: CA=Conservation Agriculture, CF=Conventional Farming, RL=Reference Land.

Figure 11, represents a graphical in-depth analysis of specific taxonomic and visualization of the relative abundance of bacteria species present in soil samples.

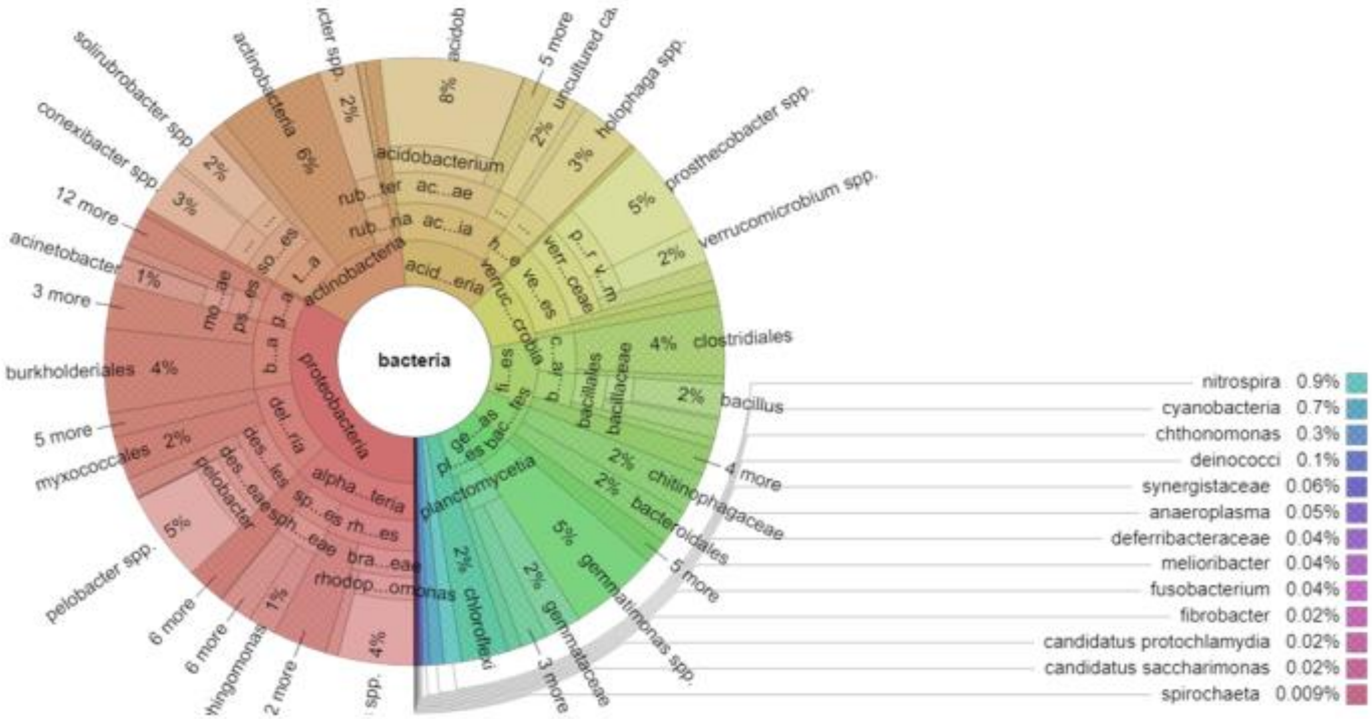

Figure 11. Graphical in-depth analysis with greater taxonomic specificity and visualization of the relative abundance of bacteria species present in soil samples.

Findings show that Rhizobium, Bradyrhizobium, Mesorhizobium, Pseudomonas, Bacillus, Azotobacter, Azospirillum, and rhizobacteria, were the mostly abundant in farms adopting conservation agriculture (CA) and the reference land (RL), with limited number in farms adopting CF. Glick, (2012), classifies these particular organisms as plant growth promoting bacteria (PGPB), that are capable of providing resilience to the field crops by enabling them to survive under various abiotic stresses.

Overall, 23 microbial populations of several species were identified under rhizobium; with 16 of these being identified under rhizobiales, a further 6 results identified under bradyrhizobiceae, while chitinophagaceae and chitinophaga spp had one each.

The findings of soil microbial analysis in the current studies established that *Acidobacter, Azospirillium, Azotobacter, Bacillus, Burkholdria, Enterobacter, Erwinia, Flavobacterium, Rhizobium and Serrotia* populations appeared to favor farms adopting conservation agriculture farming systems as compared to the farms adopting conventional farming, since their number were significantly higher in CA and in the RL. Retention of crop residue in farms adopting CA, seem to enhance soil organic carbon (Jiang *et al*., 2016). According to Onley, (2017), soil bacteria such as; *Bradyrhizobium spp,* esorhizobium *spp, pirellula,* N*itrospira, nitrosospira* species have been shown to form nitrogen-fixing symbioses with leguminous crops that are responsible for increasing nitrogen availability to plants in some soils. Furthermore, positive impact on nitrogen fixing as well as the activity of nitrogen fixing bacteria has also been reported in mulch-based conservation farming as compared to conventional farming systems in annual beans/maize cropping (Sousa *et al.*, 2016).

The rhizobacteria were more versatile in transforming, mobilizing and solubilizing soil nutrients (Hayat *et al*., 2010). Among the populations of bacteria, the relative abundance of nitrospira and *bacilli* were highest in Umande site. *Bacilli* possessing multiple plant growth promoting properties as well as biocontrol properties were observed to be significantly higher in CA when compared with conventional farming systems (Ivan *et al.,* 2019). A higher proportion of *Nitrospirae* (Nitrospira genus) found in some sites represented more active soil N cycling as reported by Zhang *et al*., (2019), while *cyanobacteria* has plant growth promoting properties, including nitrogen-fixation activity. According to Akram *et al., (*2017), *streptomyces* species are important group of soil bacteria capable of producing plant growth promoting substances, *thiobacillus* strains identified in farming soils are capable of solubilizing fixed forms of P into soluble forms which play key role in soil fertility.

Studies show that adoption of regenerative farming systems can lead to improved soil bacterial community, nitrogen capture and consequently contribute to the conservation of arable soil (Balota *et al*., 2003). Except in some species where there was general improvement in soil bacterial species, no particular farming systems had more effects on microbial populations, than the other.

Hierarchical clustering of soil bacteria:

To provide a visual overview combined with analysis we utilized a dual hierarchical dendrogram to display the predominant genera with clustering related to the different groups (figure 12). Based on the lack of distinct combined clustering between sample groups, there is no evidence suggesting a significant difference between sample groups CA and CF. Differences between sample groups between CA and CF were however addressed under relative microbial populations for species in soils.

The clustering of bacteria diversity is as shown in figure 12

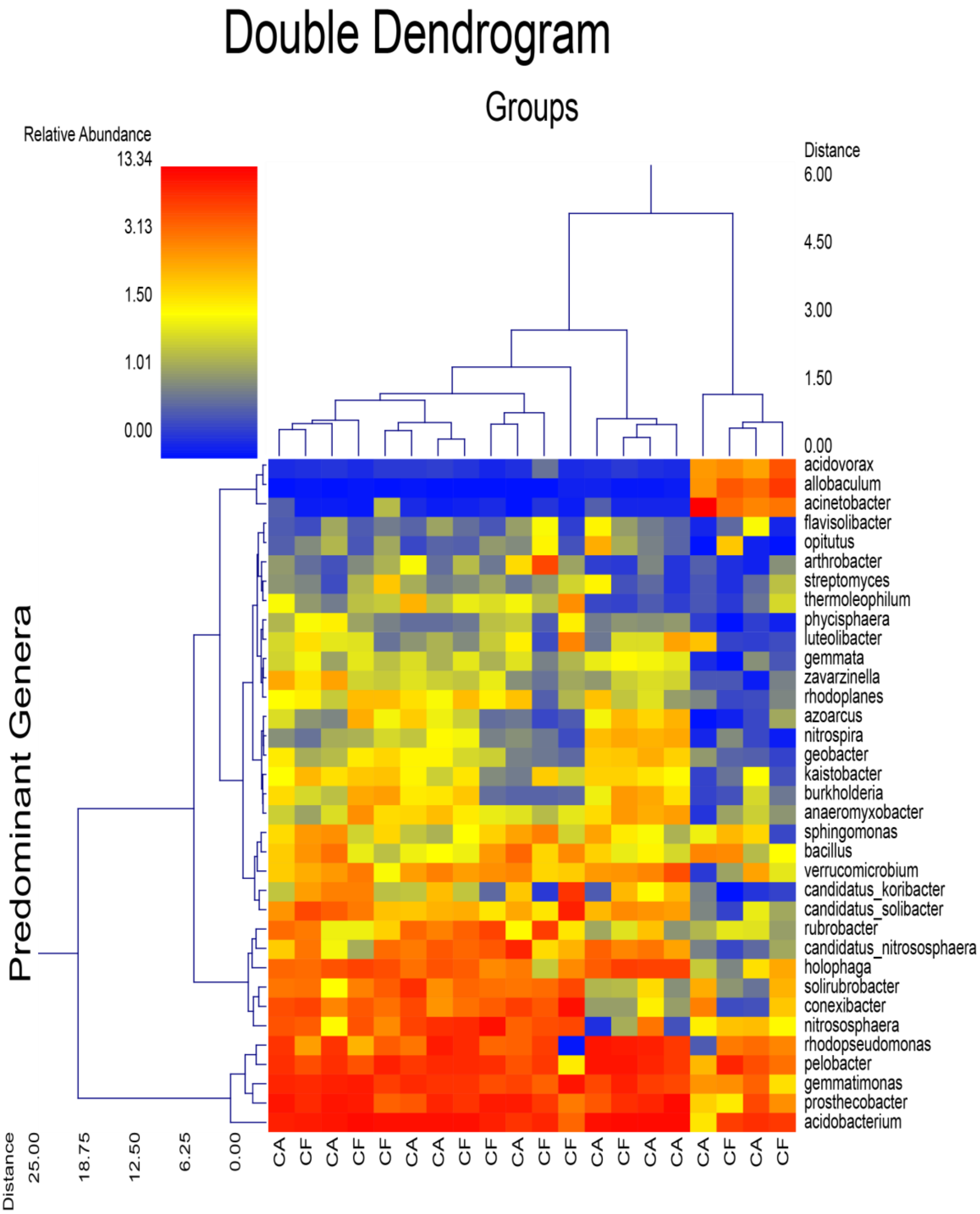

Figure 12. Clustering heat map analysis of bacterial populations under different farming systems. Analysis of the taxonomic classification data, with each sample clustered on the X-axis labeled based upon the farming treatment. The color scale, shows the relative abundance values, with yellow (low abundance), red (medium abundance), and blue (high abundance).

Samples with more similar microbial populations were mathematically clustered closer together. The genera (consortium) were used for clustering, thus the samples with more similar consortium of genera cluster closer together with the length of connecting lines (top of heat map) related to the similarity, shorter lines between two samples indicated closely matched microbial consortium. The heat map represents the relative percentages of each genus. The predominant genera are represented along the right Y-axis. The legend for the heat map is provided in the upper left corner.

4.3.2 Diversity of Soil Fungi in the Studied Farms

Variations in soil fungi population, from the analysis of soil samples corrected from farms adopting conservation agriculture and conventional farming systems are shown in Figure 13. In terms of fungi population from the studied farms, findings show that *verticillium dahliae spp*, was significantly higher in all the five sites (Figure 13).

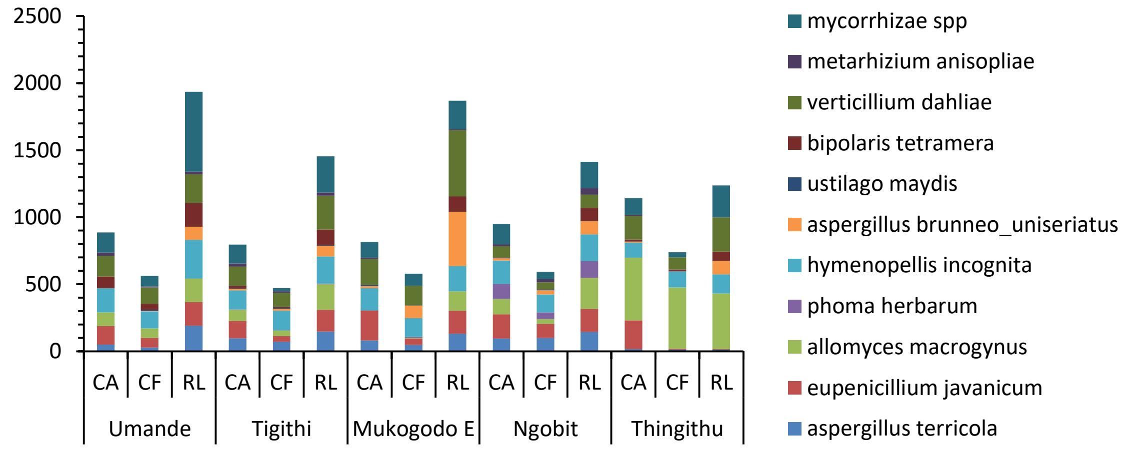

Figure 13. Fungi Populations Diversity Under Farming Systems In 5 Study Wards.

The study observed significantly higher populations of A*llomyces macrogynus* fungi in CF than in both CA and the RL at Tigithi and Umande sites with mean values of 78 and 58 organisms respectively. However, the mean population in soil was significantly higher under CA than under CF (22) at Thingithu. The population under RL was significantly higher than in CA and CF, at Tigithi (84), Umande (68) and at Mukogodo East (130). The mean population of *Aspergilus terricola* was significantly higher under RL at Tigithi (27), Umande (10), Mukogodo East (60), and at Ngobit (58). The population was significantly higher in farms adopting CA than those adopting CF at Mukogodo East (28) and Ngobit (18) wards. It was significantly higher in CF than in both CA and RL at Thingithu (18). *Ectomycorrhizae* population was significantly higher in RL at Tigithi (39), Mukogodo East (70), and Ngobit (44) and at Thingithu (30). The population was significantly higher under CF than under CA at Tigithi (15) and at Ngobit ward (20).

It was significantly higher in soils under CA farming than under CF at Umande (16), Ngobit (8) and at Thingithu (20).

"*Eupecillium javanicum*" population was significantly higher under CA than under CF and the control at Tigithi with a mean relative population of 17 organisms and at Ngobit with a mean population 19 organisms and at Thingithu with a mean population of 20 organisms. The mean number of organisms was significantly higher in RL at Umande with a mean population of 20 organisms. The mean relative number of organisms of *Metarhizobium anisopila* was significantly higher under CA farms than in CF farms at Tigithi with a mean population of 16 organisms in Mukogodo East with mean population of 19 organisms.

The population was significantly higher in CF farms, than in CA farms at Ngobit with a mean number of 15 organisms, and was significantly higher in the control than in CA and CF at Thingithu (38); at Umande with a mean number of 23 organisms and in Umande with a mean population of 44 organisms. A higher relative abundance of *Mitrososphaera spp*, in Mukogodo East, Ngobit and Tigithi wards represented more active soil nitrogen cycling, since these bacteria have been found to enhance nutrient bioavailability (Zhang *et al*., 2019; Muller *et al*., 2016). Shannon and Simpson index values were found to be higher in CA samples at the genus level, but a more diverse bacterial species were observed in the RL, which had abundant functional microbes, in agreement with studies by (Wang *et al*., 2013).

Findings from this study show that chaetomium *spp* had the highest percentage of fungi population at 22%, followed by *Mortierella alpine spp.* (6%), *phoma.spp.* (5%), while that of *Cephalosporium., aspergillus, agaricales* and *tremellales* constituted 4% of the population. Soil *"Fusarium oxysporum.spp., pencilium.sp.,* M*ortierella.sp., Spizellomyces acumin* and *hannaella* were at 3%; while *Mephalosporium curtipes. ,volutella. colletotrichoides. pleosporaceae.sp.* and *pezizales* were at 2%.

There were approximately 64 results of other organisms which were below 1% in diversity. These species can be viewed upon further editing of the interactive pie chart of fungi. The evolutionary tree used to identify fungi species from the analyzed environmental samples is shown in figure 14.

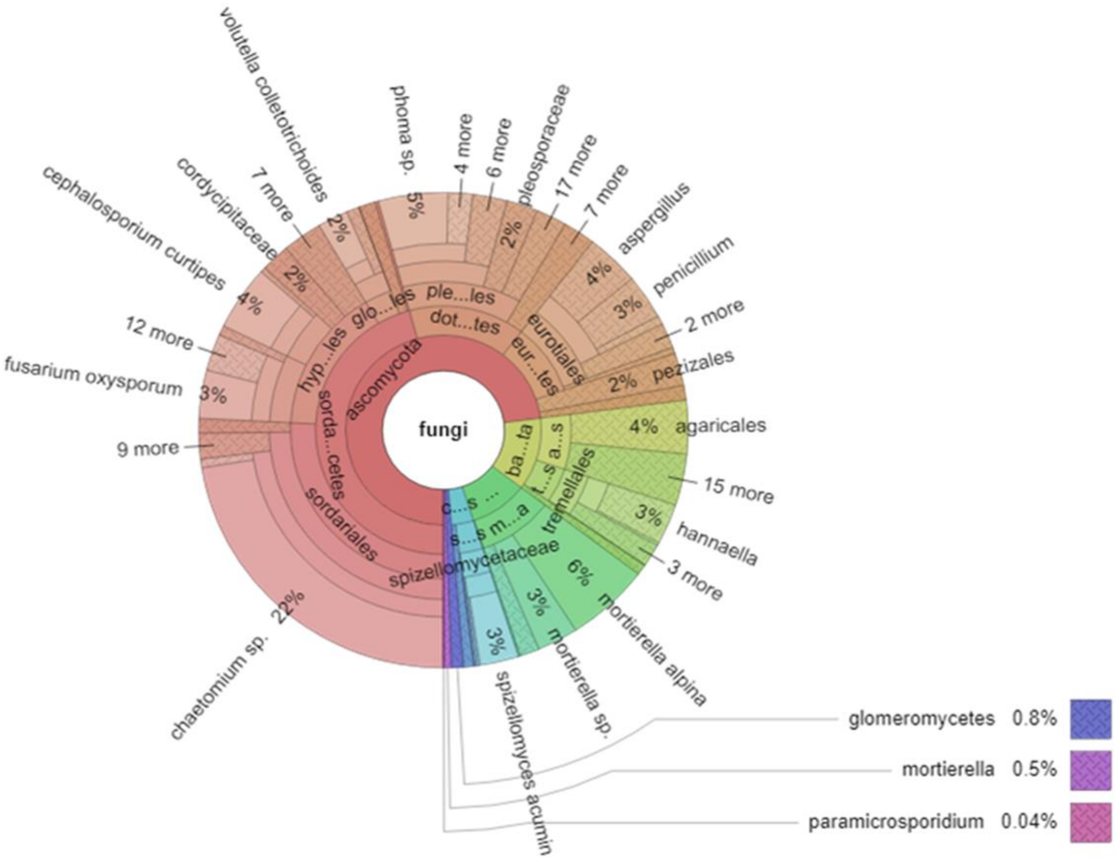

Figure 14. Evolutionary tree used to identify the possible species of fungi from the analyzed soil samples from five wards.

A good number of soil fungi in current study have been shown to play key role in agriculture, such as fixation of atmospheric nitrogen, suppression of plant diseases and soil-borne pathogens, decomposition of organic residues, enhancement of nutrient cycling and plant growth regulation (Omotayo and Babalola., 2021). Others are are able to form associations with plants and are able of influencing the primary and secondary metabolism of plants in the production of sustainable food crops (Ferreira *et al.*, 2019).

Moreover, Kumar, *et al*., 2021, showed that plant-growth-promoting bacteria *Pseudomonas* sp. and *Bacillus* promoted growth in stressed plants by producing indole acetic acid (IAA), siderophores, and solubilizing phosphates.

Fungi such as *mycorrhizae* form symbiotic relationship with plants by forming hyphae networks that aid the plant to obtain phosphate and other minerals, such as zinc and copper, from the soil (Franco-Correa *et al*., 2010). Furthermore, *mychorrhiza* bound species of *alternaria*, genus *aspergillus*, *cladosporium, gematium, gliocladium, humicola* and *metarhizium* found in the current study have been demonstrated to maintain soil organic matter (Franco-Correa *et al*., 2010; Poole *et al*., 2018).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion of the Study

Although numerous benefits associated with CA farming system have been identified in this and other studies by Thierfelder *et al.*, (2016); Giller *et al.,* (2015) and Gloveretal, (2016), a variety of challenges and hurdles to adoption of CA were revealed in the study area and included; (i) inadequate skills and knowledge of farmers to apply all the principles of CA farming system; (ii) inadequate biomass from crop residues and cover crops retention on soil surface since there is often competition between crop and livestock systems; (iii) farmers are unable to access important CA tools/implements (82.35% of soil rippers and 100% of 2-wheeled tractors are by importation); (iv) cash constraints (76% of farming are self-funding) and (v) farmer perception and choices in adopting CA. These constraints are postulated to be the main factors contributing to declining number of farmers adopting CA in the study area. These findings are however not unique to CA farming in Laikipia, but are general constraints experienced in most smallholder farming in Africa (Baudron *et al.* (2015).

Although in this and other studies by Misiko and Tittonell, (2011), have demonstrated that, farmers tend to adopt and implement new technologies based on various factors including; funds, influence from extension providers and other farmers, own understanding and interpretation of the technology benefits, capacity building to farmers and agricultural extension staff is recommended to advance promotion of CA in the study area. This is in agreement to the findings by Kaumbutho and Kienzle, 2007)

Findings show that, farms adopting CA farming system had higher levels of SOC and soil moisture when compared to those adopting CF, which agrees with findings by (Chai *et al*., 2015; Wang *et al,* 2013). These particular findings are important discovery on the role of CA in improving soil physical properties and climate adaptation. However, other studies found that effects of CA on soil carbon are dependent on the eminence of CA application and is often site-specific (Thierfelder *et al.* 2014). There is however, general consensus among scholars that CA has positive impacts on soil organic carbon in the medium to long duration but is often more definite in areas with low rainfall (Steward *et al*. 2018). In other studies, reducing tillage without increasing biomass use may only have a short-term effects on soil organic carbon rearrangement to the top layer and therefore the long-term potential for carbon sequestration and reduction of soil bulk density is still debatable (Luo *et al*., 2010; Kamiri *et al*., 2022). Finding in this study have shown that the use of reduced tillage and crop cover or residue and diversification of crop species in CA, generally led to increased soil organic carbon and microbial diversity compared to CF. This is in agreement with other studies by Jacobs *et al*., (2010), and Zhang *et al*., (2021).

Overall, adopting CA can improve soil organic carbon and soil moisture critical in productivity, which has the potential of enhancing crop productivity in arid rain fed farming. However, adopting CA farming as compared to CF farming can contribute to higher soil BD, postulated to be result of soil compaction during farm operations.

The results on the effects of farming systems on soil exchangeable cations were unpredictable as far as farming systems were concerned. This is thought to be due to farming practices that might have effects on soil elements such as; fertilizer application, tillage and irrigation which might have additional effects than the natural factors in influencing the exchangeable cations in farming systems, according to Gol, (2009).

Transition from CF to CA according to Shekoofeh *et al*., (2012) can provide soil health benefits associated with crop resilience to biotic and abiotic stresses and ecological fitness in the lowland rain-fed farming. Several studies have shown that, adherence to early land preparation, dry planting, supplemental use of farm yard manure, water and soil conservation, agro-forestry, and employment of dryland farming technologies such as, Zai pits and other water harvesting technologies, are important agronomic practices that can complement CA principles to soil properties and increase productivity and resilience to climate effects (Kadiri *et al,* 2021; Tanveera *et al.,* 2016; Luo *et al.,* 2010; Mo *et al.,* 2016; Okeyo *et al*., 2014; Kiboi *et al*., 2017; Araz., 2014).

The study found a diversity of fungi and bacteria populations whose presence in the soil is a good sign of soil health in farming systems. The study established that some strains and genera, associated with promotion of plant growth, solubilizing phosphate and providing soil bio-remediation (Abdel-Rahman *et al*., 2017 and Bainard, *et al.,* 2017), were significantly high in soils under CA than those in CF.

5.2 Recommendations

In response to limitation in soil moisture in the study area, the study recommends continued support by government and private sector in sinking of farm pods and water pans for use in crop irrigation since rainfall is in short supply and the amounts received are relatively low. Promoting a combination of TIMPs among farmers in the study area, is one way to help them improve soil moisture content in the soil, and increase crop productivity. Ploughing, which is a key farming practice among farmers adopting CF amid other practices should be done such that there is a contentious adjustment of plough depth to reduce the development of soil hard pans and increase soil moisture infiltration. Crop residue management, reduced tillage combined with water harvesting strategies by farmers can improve soil moisture conservation, (Kuria *et al*., 2022; FAO, 2019; Abdullah, 2014). Further studies are recommended to evaluate more ecological factors which that can influence soil moisture dynamics not considered in this study.

Since findings of this study and other studies by Ashraf *et al.*, (2015), Meijer *et al.*, (2015) and Spurk *et al.*, (2020) have shown that farmers receive technical advisory services from public extension sources, effective communication of agricultural information and advisory services to farmers are therefore vital in dissemination and adoption of sustainable agricultural technologies. Any policy decision made by government and stakeholders to promote adoption of CA farming, will be considered as an effective way to disseminate knowledge for up-scaling CA farming technology in the study area. As to how effective the dissemination of the study findings can be done in the current situation where CA adoption among farmers has been declining, depends upon what efforts and methods of disseminating information will be undertaken.

Integrated approach to soil fertility management and continuous improvement of CA principles is recommended. Adoption of CA technology may require employment of complementary soil fertility management strategies, to achieve holistic soil fertility. This requires continuous adaptation of farming technologies by farmers depending on their capacity to receive technical information make informed decisions. Support and incentives for youth farmers is therefore necessary in the study area.

Government policies and stakeholders efforts are required to support gender mainstreaming in agriculture and provide equity to women farmers to own land for farming.

Since findings showed that land use change from CA farming systems to CF farming system stimulated active effects in spatial distribution of SOC and soil moisture in the root zone, (<0.2 m) and rarely considered the vertical distribution of deep soils below 20cm, further studies can be carried out to determine SOC in lower soil depth. The selected microbial organisms from a host of environmental species in this study, play a major role in agricultural soils, are useful and can directly affect nutrient dynamics, soil structure and plant growth. Adopting CA would therefore encourage proliferation of soil useful organisms in the study area. The study recommends further studies be undertaken to evaluate the effects of farming systems on soil properties, in soils deeper than 20cm, evaluated in the current study.

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APPENDICES

Appendix 1. Data Collection Questionnaire (Page 1)

I. DATA COLLECTION TOOLS

(Sample Questionnaire)

Questionnaire Serial No. …………

This questionnaire is strictly for academic purposes. The information you provide will be treated with confidentiality, so feel free and be as truthful as possible. Thank you.

PART 1: FARMER'S BASIC INFORMATION

i. Please indicate your name (Optional) ………………..…………………

ii. Please indicate where you are located (Ward) ……………….………………….

iii. Please indicate your gender Male ( ) Female ( )

PART II: ADOPTION AND UNDERSTANDING OF FARMING PRACTICES

1) What farming system do you practice?

☐ Traditional / Conventional Farming (CF)

☐ Conservation Agriculture (CA)

☐ Both CA & CF

☐ Others (Specify)

…………………………………………………………………………………………

2) How do you practice Conventional Farming (CF)?

…………………………………………………………………………………………

…………………………………………………………………………………………

3) What kind of tools/Implements do you use in Conventional Farming?

…………………………………………………………………………………………

…………………………………………………………………………………………

4) If you practice conservation agriculture (CA), do you practice all the principles of CA?

☐ YES NO ☐

Appendix 2. Data Collection Questionnaire (Page 2).

5) If YES above, describe the three principles of Conservation Agriculture, that you practice.

a. ……………………………………………………………………………………

……………………………………………………………………………………………

b. ……………………………………………………………………………………

……………………………………………………………………………………………

c. ……………………………………………………………………………………

……………………………………………………………………………………………

6) If CA, for how long have you practised it?

☐ For 0-5 yrs ☐ for 5 – 10yrs ☐ Over 10 yrs

7) If CA, why do you practice it?

……………………………………………………………………………………………

……………………………………………………………………………………………

8) Please mention the tools/equipment you use in your CA practice?

……………………………………………………………………………………………

……………………………………………………………………………………………

9) Please explain the use of each CA tools or equipment?

……………………………………………………………………………………………

……………………………………………………………………………………………

10) What crops do you cultivate under CA?

……………………………………………………………………………………………

……………………………………………………………………………………………

11) How do you compare crop yields in conventional farming with CA?

……………………………………………………………………………………………

……………………………………………………………………………………………

12) Do you keep farm records? YES. ( ) NO. ( ) (if yes, provide a copy for perusal)

Appendix 3. Data Collection Questionnaire (Pg. 3).

13) Do you apply any fertilizers in your farming practice? YES.( ) NO.( )

14) If YES above, when did you apply fertilizers last?

……………………………………………………………………………………………

……………………………………………………………………………………………

15) If you applied any fertilizers, what type (s) of fertilizers did you use?

a. This season?………………………………………………………………………………

……………………………………………………………………………………………

a. Last season? ………………………………………………………………………

……………………………………………………………………………………………

16) . Do you apply any type (s) of manures?

a. This season?…………………………………………………………………………………
…

……………………………………………………………………………………………

b. Last season? ………………………………………………………………………

……………………………………………………………………………………………

17) Have you ever applied agricultural Lime in your farming? YES.() NO.( )

18) If YES, when did you apply agricultural Lime? ………………………………………………

……………………………………………………………………………………………

19) What amounts of agricultural lime did you apply (kg/acre)?

……………………………………………………………………………………………
……………………………………………………………………………………………

Do you grow crops in pure or mixed stands? YES. ( ) NO. ( )

Do you grow crops continuously on your farm? YES. ( ) NO. ( )

Name the Crops you cultivated.

Appendix 4. Data Collection Questionnaire (Pg. 4).

This Season (
)……………………………………………………………………………………………………
……………………………………………………………………………………………

Previous Seasons (
)……………………………………………………………………………………………

……………………………………………………………………………………………………

PART IV: USE OF AGRICULTURAL INPUTS

Do you apply any fertilizers or manures in your farming practices? YES. ( ) NO.( )

If YES (above), when did you apply lastly? This Season ( ). Previous Seasons ( ).

If YES (above), what type of fertilizers or manures did you apply?

This Season.

…………………………………………………………………………………………

……………………………………………………………………………………………………

Previous Seasons

…………………………………………………………………………………………

……………………………………………………………………………………………………

Have you ever applied agricultural Lime?

This Season ( ). Previous Seasons ( ). Never ( ).

Appendix 5. Image of NACOSTI Student Research Permit.

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