IMPACT OF WATER HARVESTING AND SOIL FERTILITY MANAGEMENT TECHNOLOGIES ON INTERCROPPING SORGHUM AND COWPEA PRODUCTION IN EMBU AND KIRINYAGA COUNTIES, KENYA

By

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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To My Love Corlinear Wanjeru and my children; Fridah Wawira, Victoria Wanja, Ann Leakey Nyakio and Rihanna Ngendo.

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LIST OF ABBREVIATIONS AND ACRONYMS

AE	Agronomic efficiency
AEZ	Agro-Ecological Zone
AISP	Agricultural Input Subsidy Program
BCR	Benefit-cost Ratio
CAADP	Comprehensive African Agricultural Development Programme
CF	Contour Furrow
CBO	Community Based Organizations
EAAPP	East African Agricultural Productivity Programme
ESA	Eastern and Southern Africa
FAO	Food and Agriculture Organization
FP	Farmer Practice/Conventional tillage
FYM	Farm Yard Manure
GDP	Gross Domestic Production
ISFM	Integrated Soil Fertility Management
K	Potassium
KARI	Kenya Agricultural Research Institute
LM4	Low Midland 4
LSD	Least Square Difference
MHPDP	Medium to High Potential Areas with Declining Potential
N	Nitrogen
NGO	Non-governmental organization
NRM	Natural Resource Management
P	Phosphorous
SAL	Semi-arid Lands
SSA	Sub-Sahara Africa
SWC	Soil Water Content
SOC	Soil Organic Carbon
TR	Tied ridging
UM3	Upper Midland 3
UM4	Upper Midland 4
WAP	Weeks after planting

ABSTRACT

Climate change coupled with poor soil fertility, shrinking natural resource base, ineffective markets, institutional weaknesses, and inadequate policies are the key drivers to sub-optimal agricultural productivity. Sorghum (*Sorghum bicolor* (L.) Moench) and cowpea (*Vigna unguiculata* L.) production continue to experience intransigent production problems. This study was carried out in Mbeere South and Kirinyaga West Sub-Counties classified as semi-arid lands and Medium to high potential areas with declining potential (MHPDP), respectively. This research aimed to determine the effect of soil water harvesting and integrated soil fertility amendment practices on: - i) Sorghum and cowpea yields, ii) Soil chemical properties and soil water content at different soil depths, iii) Farmers evaluation criteria for ranking and evaluation of treatments, and iv) The cost benefit returns during LR 2011, 2012 and LR 2012. The study involved experimentation approach and farmers' evaluation of the study treatments in the scale of good, fair and poor using a structured questionnaire. The treatments were arranged in a 3 x 2 x 6 factorial structure. The main factors were three water harvesting (i.e., Tied ridging, Contour Furrows and Farmer Practice), two cropping patterns (Mono-cropping and Inter-cropping) and 6 soil fertility management options (Control, 40 kg P ha^{-1} + 40 kg N ha^{-1}, 40 kg P ha^{-1} + 20 kg N ha^{-1}, 40 kg P ha^{-1} + 40 kg N ha^{-1} + Manure 5 t ha^{-1}, 40 kg P ha^{-1} + 20 kg N ha^{-1} + Manure 2.5 t ha^{-1} and manure 5 t ha^{-1} laid out in a partially balanced incomplete block design (PBIBD), replicated thrice. Soil moisture was measured at soil depth of 100 cm at 10 cm intervals using Diviner 2000 at fortnight interval of 2 weeks after planting. Soil samples were also collected and a composite sub-sample derived at a depth of 0-20 cm for soil elements analysis for each treatment at the beginning and end of experiment. Sorghum and cowpea productivity was measured at physiological maturity, and cost of production data was collected during the experimentation period to determine cost benefit return. Data were analyzed using ANOVA and significant means separated using Least Significant Difference (LSD) at 95% Confidence Interval. There were significant effects (p=0.051, p=0.001 and p=0.0314) of soil water harvesting techniques, cropping patterns and soil fertility amendment options on sorghum height during the SR 2011 respectively, and significant (p=0.0001) during the LR 2012. However, soil fertility amendment practices had significant effect (p=0.0003, p=0.0001 and p=0.0001) on sorghum grain yields during the LR 2011, LR 2012 and SR 2011, respectively. There was also a significant interaction effect (p=0.0047) and (p=0.0047) on cowpea productivity during the SR 2011 and LR 2012 seasons, respectively. Soil pH, N, total C and available P increased significantly (*t-test*, $p<0.05$) in manure treatments except in the "controls" at the end of experiment. Soil water content measurements was a significantly higher at initial stages of 2 WAP, 4 WAP and 6 WAP intervals in relation to the late stages of the season. On farmers treatment evaluation, biophysical sorghum grain yields (t/ha) and farmers treatment evaluation had a significant positive correlation (r>0.5, p<0.0001) on individual treatments. However, there was a significant relationship where farmers evaluation and ranking of treatments highly depended on his/her gender and education level (Pearson X^2>15.4, p<0.0001). The treatments of the study showed significant effect (p<0.0001) on net benefit, benefit cost ratio and return to labour were significantly. This study demonstrated that soil water harvesting techniques, cropping patterns and integrated soil fertility amendment practices have positive influence on sorghum and cowpea productivity in Central Kenya Highlands and is cost-effective.

CHAPTER 1: INTRODUCTION

1.1 Background to the Study

In Sub-Saharan Africa (SSA), approximately 315 million individuals, representing one out of every two people, live on less than one dollar per day (FAO, 2008). Moreover, the number of undernourished individuals has risen from around 170 million during the period in 1992 to surpass 200 million in 2003 (FAO, 2008). The overall poverty rate in 2019 was 33.6 per cent, implying that 15.8 million people lived below absolute poverty line. The overall poverty incidence remained highest in rural areas at 37 per cent and 26 per cent in urban areas respectively (Kenya Poverty Report, 2019). Agriculture contributes to 55% of the Kenya's Gross Domestic Product (GDP); where 26% and 27% contribution to the economy is direct and indirectly, respectively (FAO, 2022; World Bank, 2018). Agricultural sector is also a source of employment to ~40% of the total population and ~70% of Kenya's rural people. Therefore, agriculture in Kenya is broad and diverse, with stakeholders spanning public sector, government corporations, not for profit organizations and private sector (World Bank, 2018; FAO, 2022).

Maize production in SSA is characterized by grain yields of less than 2000 kg ha^{-1}, about 100% below global average ~5500 kg ha^{-1} maize production (FAO, 2021). As of 2018, the per capita average maize production was 80 kg $person^{-1}$ $year^{-1}$, compared to the recommended 103 kg $person^{-1}$ $year^{-1}$ (GoK, 2020). This translated to an annual production of about 2 t ha^{-1} against the expected 6 t ha^{-1} (Nyaanga and Barasa, 2019). According to Muindi *et al*. (2015), Njogu (2019) and Cairns *et al*. (2021), the persistent declining maize production is attributed to population increase, soil degradation, climate variability, pest and diseases associated with climate variability, insufficient capital to purchase agricultural inputs and soil nutrient mining without nutrient re-application.

The Agriculture sector contributes 65% of the export income, and is a source of livelihood for >80% of the Kenyans (FAO, 2021). It is also the main driver of the non-agricultural economy such as manufacturing, providing raw materials and a market for non-agricultural sectors for instance building/construction, transportation, tourism, education, and others. The dynamics of poverty in Kenya are changing and directly affect the Kenya's agriculture. By 2022, 46% of the Kenyan population lived below one USD day^{-1}, 36.5% being food insecure while 35% of children under age of five years were stunted in Kenya (FAO, 2022). According to FAO (2008) Kenya's population will be double by the next three decades, reaching 81 million before 2050. These dynamics will increase pressure on the available arable lands in high agricultural potential areas leading to a potentially negative implication on food production.

Semi-arid areas are dominated by erratic rains which are usually low and unreliable (Wamari *et al.,* 2012). The onsets of the cropping seasons and their durations are also substantially unpredictable from location to another (Mujdeci *et al*., 2010). As a result of these fluctuations more than three-quarters of attainable crop yield declines are reported (Barron *et al*., 2003). Low crop yields in Central Kenya are attributed to a myriad of factors as outlined in Kibunja *et al.* (2010). There is very little evidence currently reported on drought occurrences and options to increase rain water use efficiency in Africa (Manyatsi *et al.,* 2011). The drastic change of mixed crop-livestock systems has been estimated to see declining agricultural productivity in most of East Africa regions as a result of climate change by 2050 (Thornton *et al*., 2010; Njeru *et al*., 2013b). Therefore, continuous occurrence of drought in central Kenya has been pointed out as a constraint to agricultural production (Kisaka *et al*., 2015). This has led to low soil moisture availability to plant root zone limiting nutrients uptake by the crops (Singh *et al*., 2018; Ngetich *et al*., 2014a).

Smallholder farmers practicing rain-fed agriculture in Kenya have moved into dryer, more marginal lands which are highly susceptible to drought and other climate change hazards. In view of this, the Kenyan government's Agricultural Input Subsidy Program (AISP) aims at supporting farmers to access agricultural inputs such as synthetic fertilizers (GOK, 2018) to cushion the farmers against climate hazards. This is in line with the government's vision to industrialize Kenya through agricultural development (CAADP, 2008).

Persistent rural poverty in central Kenya is as a result biophysical cause of declining soil fertility and crop production among others leading to lower poverty levels. This coupled with a deteriorating natural resource base are major problems confronting Kenyan rural populations today. However, how to maximize on-farm soil water harvesting structures and ISFM to increase agricultural production in the Central Kenya remains an open question (Taddele *et al*., 2015). The declining crop productivity in central Kenya is also as a result failure to employ proper agronomic practices in most of our farming systems (Matusso *et al*., 2012). Most of these farming systems are characterized by long-term nutrient mining (Mugendi *et al*., 2011). Alternatively, as a result of farmers lacking finances to buy mineral fertilizers there is limited addition of external inputs into the soil (Mugendi *et al*., 2010). Also, majority of the farmers do not use fertilizers in their farms as a result lack of resources to buy inorganic fertilizers (Crew and People, 2004; Sanginga *et al*., 2009).

According to Miriti *et al*. (2012) smallholder farmers do not have access to adequate fertilizers and good quality manure in Central Highlands of Kenya,. This has been partially led to poor land productivity due to loss of soil nutrients through surface run-off and soil erosion in cultivated areas further leading to crop yields below average levels (Muindi *et al*., 2017). According to Githunguri *et al.* (2020) Kenya has a relatively lower average productivity of major staples foods relative to the other countries in the East Africa region. For example, the observed yields for most cereals in most farmers' fields hardly exceeds 500 kg ha^{-1}, yet an attainable yield of 8000 kg ha^{-1} is achieved in research stations and in large scale producers (Taddele *et al.*, 2015). A similar pattern is observed for legumes such as beans whose production is less than 0.300 kg ha^{-1} whereas the potential of most varieties is about 2000 kg ha^{-1} (Githunguri *et al.*, 2020). This is a huge yield gap between the experimental station, potential yields in farmer fields, and actual yields in farmer fields. Low productivity could be associated with poor soil fertility, low technology diffusion, slow adoption of new technologies and the agricultural lands that are susceptible to harsh weather conditions (Taddele *et al.*, 2015; Masvaya *et al*., 2017).

Farmers' motivation to invest on crop land has been hindered by high drought incidences in Kenya (KARI, 2009); where yield-limiting droughts have been reported to affect three-quarters of cropping seasons every two decades (GoK, 2020). Therefore, on-farm irrigation systems could be available options for maintaining appropriate soil moisture in the rhizosphere to support crop growth and development. This is not practical to most of domestic farmers as a result of lack finances to purchase irrigation kits or scares water for carrying out irrigation (Njeru *et al*., 2018). This challenge maybe addressed by the adaptation of appropriate on-farm water conservation methods and ISFM techniques to cope up with climatic conditions for increased high valued traditional crop productivity (Biamah *et al*., 2000).

1.2 Statement of the Problem

Persistent drought occurrences have resulted to low crop productivity in most of agricultural lands. One of the major constraints is unreliable and limited understanding of spatial and temporal rainfall distribution per seasons. The main challenges to smallholder farmers is to increase crop productivity while using less water per unit of output within a growing season e.g. Drip irrigation. They lack reliable and limited understanding of spatial and temporal rainfall distribution per season which leads to reductions of crop yields up to 75%. Therefore there is need to incorporate water harvesting and ISFM practices in farmer's fields to increase crop yields. These practices include mulching and tied ridging on maize and cowpea production among others (Miriti *et al*., 2011; Singh *et al.,* 2018).

Low crop productivity is mainly due to soil fertility degradation which remains a major biophysical cause of declining soil fertility. High loss of nutrients occur due to nutrient mining without adequate replenishment, continuous cultivation, removal of crop residues, poor soil & water conservation techniques and poor agronomic practices such as lack of appropriate knowledge on cropping systems. These problems are further aggravated by the rising cost of inputs or farmers abandoning the use of inorganic and organic fertilizers has also resulted to reduction in crop productivity (Naudin *et al*., 2010; Mugwe *et al*., 2009a).

The cost benefit analysis information on practices that can improve yields of sorghum and cowpea production in central highlands of Kenya remains scanty. Even though there is potential of improving sorghum and cowpea production through use of soil water harvesting and soil fertility management practices, scanty information exists on how best these techniques can be optimized for maximum returns on sorghum and cowpea production. In addition, there is scanty information of farmer's perception on soil and water harvesting and ISFM technologies and how these perceptions relate to scientific findings on sorghum and cowpea production. The purpose of this study was therefore to investigate the effects of various soil water harvesting and soil fertility management technologies on intercropping sorghum and cowpea in Kenyan Central Highlands.

1.3 Justification for the Study

To increase sorghum and cowpea production in central of Kenya remains a challenge to ensure rural poor economic growth, food security and biodiversity conservation. However, most of the recent research and development programmes focus on crops such as maize and common bean (Muui *et al*., 2013; Njeru *et al.*, 2016). As a result, there is limited investments on sorghum and cowpea, which are "high valued traditional/neglected crops" especially in the arid and semi-arid areas. The two crops are essential for food and nutrition security and an income source for smallholder farmers in central Kenya. Crop diversification through incorporation of the two crops cushions farmers against crop failure during extreme weather events.

Sorghum has mechanisms of adaptability during the dry periods of the season and resume it growth when there is no soil moisture stress unlike maize which succumbs to moisture stress. It has an extensive and widespread rooting system and waxy bloom on leaves that reduces transpiration and minimizes water losses (Paterson, 2008). In addition, there is an upcoming new market from brewing companies and farmers are unable to meet the market demand (Esilaba *et al.,* 2021). This predicts shift cultivation to sorghum production in future in central Kenya from the originally cultivated maize crop. Therefore, this study was involved in identifying gaps on promising SWH and

ISFM strategies that cope up with water stress to sustain sorghum and cowpea yield stability in Kenya's central highlands.

The focus on these factors was intended to result in an increased knowledge of the interactions between soil factors (Muindi *et al*., 2017). The expected output of this study will assist smallholder farmers and other stakeholders to create and experience development impacts from sorghum and cowpea production and efficient markets. This is expected to be attained through a focus on and giving more considerations to the interconnections among government institutions, NGOs and CBOs on sorghum and cowpea value chains, sustainable natural resource management and policy makers. Cumulatively, these efforts will support the Kenyan government's Vision 2030.

1.4 Research Questions

This study aimed at answering these questions:

i. How do soil water harvesting techniques, integrated soil fertility amendment practices and cropping patterns influence sorghum and cowpea yields?

ii. How do various soil water harvesting techniques, integrated soil fertility amendment practices and cropping patterns affect soil chemical and selected soil physical properties?

iii. To what extent do the farmer's rankings compare with biophysical data on crop performance under various soil water harvesting techniques and integrated soil fertility amendment practices for sorghum and cowpea production in the selected study sites?

iv. How do different soil water harvesting techniques and integrated soil fertility amendment practices under sorghum and cowpea production systems influence the costs and benefits in the selected study sites?

1.5 Research Objectives

The current study broadly investigated how various SWH and ISFM techniques affected the production of sorghum and cowpea in Mbeere South and Kirinyaga West Sub-Counties of Central Kenya Highlands.

1.5.1 Specific Objectives

The specific objectives that guided the study are:

i. To examine the effect of soil water harvesting techniques, integrated soil fertility amendment practices and cropping patterns on sorghum and cowpea yields
ii. To determine the effect of soil water harvesting techniques, integrated soil fertility amendments practices and cropping patterns on selected soil chemical and selected soil physical properties
iii. To evaluate how farmers' rankings on crop performance of sorghum and cowpea productivity under selected soil water harvesting techniques and integrated soil fertility amendments practices align with biophysical data
iv. To quantify the costs and benefits of different soil water harvesting techniques and integrated soil fertility amendments practices under sorghum and cowpea productivity

1.6 Research Hypotheses

The hypotheses tested in the current study are:

i. Tied ridging and contour furrows in combination with 40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1} under mono-cropping system significantly increases sorghum yields
ii. Tied ridging and contour furrows under sorghum and cowpea inter-cropping significantly increases soil water content and selected soil chemical elements and soil physical properties
iii. Farmer's rankings and scientific biophysical data on sorghum and cowpea productivity are not significantly different
iv. Farmers practice/conventional tillage in combination with 40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1} under mono-cropping pattern economically viable for sorghum and cowpea productivity.

1.7 Significance and Anticipated Output

The research will introduce affordable and sustainable production systems that will address and contribute to scientific knowledge on selected soil water harvesting structures, ISFM techniques and cropping patterns on sorghum and cowpea yields in Central Highlands of Kenya. This will form an entry point for smallholder farmers, researchers and other stakeholders seeking to understand sorghum and cowpea productivity in the two study sites. These results will also form a base for cultivation of sorghum and cowpea as a way of mitigating climate change. The information generated will assist extension services providers, researchers, brewing companies and policy makers in NRM in designing effective and efficient policies which can facilitate adoption of these technologies. This will lead to smallholder farmer's income generation at household level which will translate to improved livelihood and food security in study sites. The main focus will also include improving government policies on food security and also by targeting government vision '2030'.

1.8 Definition of Terms

Aridity index: refers to the ratio of precipitation to the potential evapotranspiration.

Climate Variability: Changes of climate elements especially rainfall distributions due to natural or human-induced processes.

Diviner 2000: refers to equipment used for measuring SWC under any experimental trial.

Dry Spell: A period during the cropping season when there is no rainfall between 10–28 days.

Semi-Arid Lands: regions characterized by a moisture limited cropping season of 75–180 days, with mean monthly temperatures of >20° C at least during the growing period and the evapotranspiration is 2 to 20 times higher than the mean annual rainfall.

Soil Nutrients: These are naturally occurring minerals in the soil needed by plant for growth and development.

Soil Water Harvesting Techniques: These are on-farm in-situ rain water harvesting structures that captures runoff water and catches the rain drops where they hit the ground.

1.9. Conceptual Framework

The interactions of soil water management, soil fertility and cropping patterns affect crop productivity (Karuma *et al.*, 2014; Kenya Meteorological Department, 2013) including sorghum and cowpeas. These include climate related factors (such as rainfall variability, soil moisture content), poor farming practices, water conservation practices. The current study integrates these factors within the four (4) objectives that focuses on crop yields, soil fertility properties, farmers' perception and cost benefit analysis on sorghum and cowpea production in central highland of Kenya. The combination of field experiments results from crop yield analyses, soil properties, farmers perception results from experimental rating of treatments and cost benefit analyses will help in the selection of the most cost-effective soil water conservation, cropping patterns and soil fertility management regimes that will provide the best bet technologies for adoptions by smallholder farmers for adoption in enhancing sorghum and cowpea productivity in Eastern Kenya (Figure 1.1).

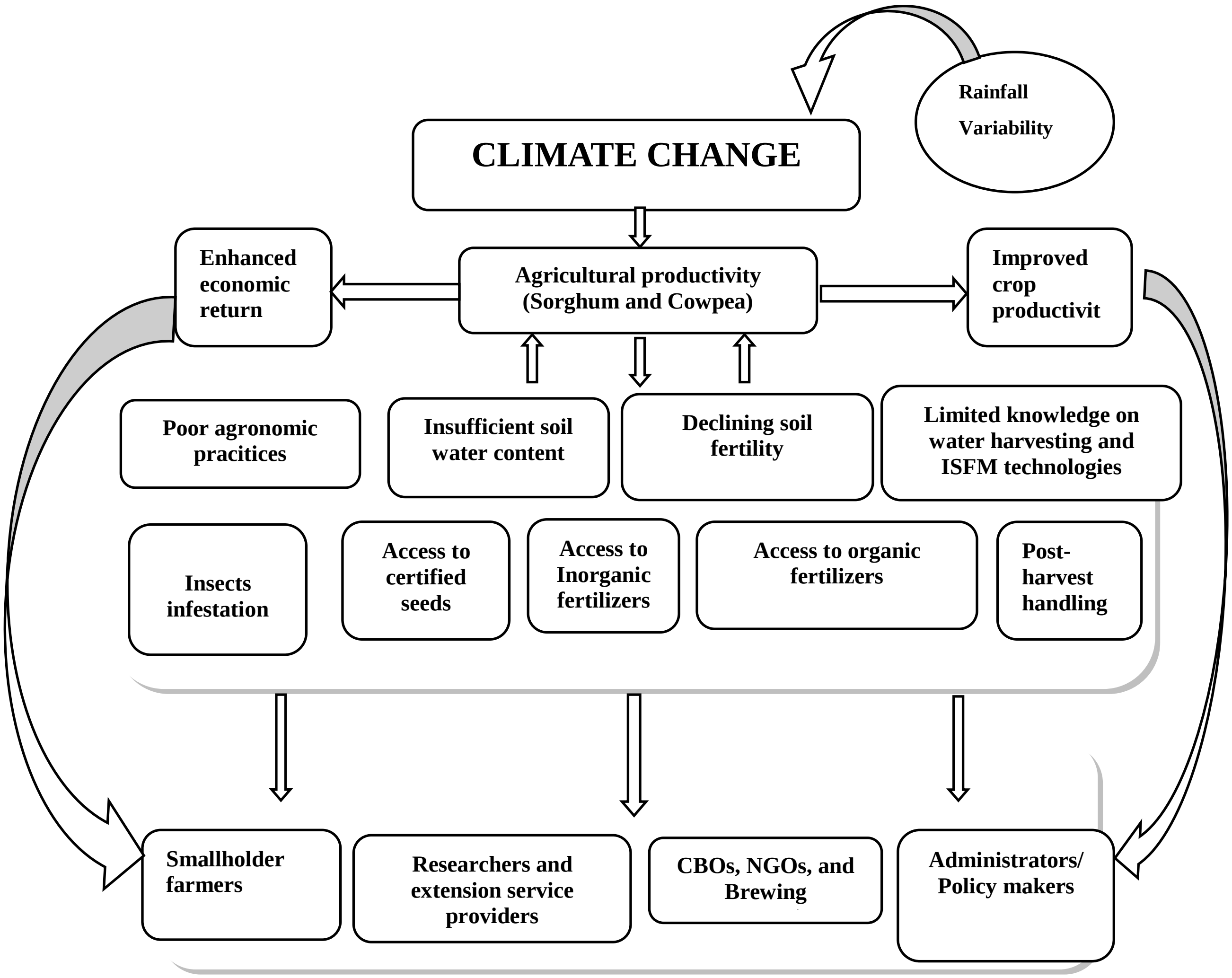

Figure 1.1: A Conceptual Framework Showing Relationship of the Study Variables (Njeru. 2025)

CHAPTER 2: LITERATURE RIVIEW

2.1 Soil Water, Nutrients Interactions on Crop Production in Central Kenya

2.1.1 Role of Soil in Crop Production in Central Highlands of Kenya

Soil is the primary source of plant nutrients, supplying 15 out of the 18 nutrients required for growth and the sources of nutrients taken up by plants include the soil mineral fraction (coming out of weathered rock), soil organic matter arising from decomposing dead organisms, inorganic fertilizers and organic fertilizers (Benish, *et al*., 2022). Another source is atmospheric deposition which can act as a significant source of nitrogen and sulfur in industrialized areas; (Global Soil Partnership, 2016).

Plants take up nutrients from soil water or soil solution that is associated with the rooting zone in the ionic form, as positively (e.g. Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Zn^{2+}, Fe^{2+}, Mn^{2+}, Cu^{2+}, NH_4^{+} etc.) or negatively (e.g. PO_4^{2-}, SO_4^{2-}) charged ions, hence the need for moisture as a critical requirement for the healthy growth of plants (Global Mechanism, 2016; Njeru *et al.,* 2024). In most situations, roots do not take up minerals directly from the soil, but work in association with soil microbes which play a critical role in transforming the mineral forms available in the soil into more plant-available forms (Benish, et al., 2022). Beyond controlling availability of plant nutrients, soil pH also controls other soil based activities such as soil enzyme activity, microbial processes involved in nitrogen cycling (i.e. nitrification and denitrification), ammonia volatilization, rhizosphere processes, biodegradation of organic pollutants and mineralization of organic matter (Neina, 2019; Reid and Hayes, 2003; Muriuki and Qureshi, 2001).

Drylands of central Kenyan highlands produce ~20% of many crops grain in Kenya, and are spread across geographies ranging from low to high agricultural potential according to Jaetzold *et al*. (2006). Maize (*Zea mays*, L.) is one of the key staple crops after rice and wheat, that accounts for about one-third of the total grain yields produced globally (Kihara *et al*., 2012). Maize is cultivated on more than 142 m ha^{-1} of land globally, producing about 637 million Mg of grain (FAO, 2021). Besides being a staple food crop in many low-income countries, many crops are used as a livestock feed (Heng *et al*., 2009), and in the production of biofuels.

2.1.2 Rainfall Distribution Patterns

By 2050, the average rainfall in SSA is projected to decline by about 10%, causing 17% reductions in drainage (Ndung'u *et al.,* 2023). According to Heng *et al.* (2009), climate related soil moisture stress has been associated with recent declines in sorghum yields in SSA. A scenario Mairura *et al*. (2021) attributed to insufficient and erratic rainfall and thus a need for climate adaptation measures for smallholder farming systems in the central highland of Kenya (Mairura *et al*., 2021). Sub-optimal sorghum yields in central Kenya in areas with adequate rainfall distribution is attributed to inadequate soil water conservation practices (Mairura *et al*., 2022).

The start and the end of the growing season are the key determinants of rainfall distribution within a season. More than 80% of Kenya's land surface is categorized as SALs (Ngetich, 2012). These regions are characterized by low and unpredictable rainfall ranging100–900 mm per year, high evapo-transpiration, sparse vegetation cover and fragile ecosystems (Kenya Meteorological Department, 2013). These areas cannot sustainably support rain-fed agriculture (Kenya Meteorological Department, 2013). Thus, crop production is constrained by extremely variable rainfall dates, uneven rainfall distribution and prevalent droughts incidences during the growing season (Karuma *et al*., 2014; Mugwe and Oduor, 2021).

2.1.3 Soil-nutrient Interaction on Crop Growth

Although soil moisture is primarily the most important resource in crop production in the SALs, the inherent soil nutrient deficiency also limits crop growth. According to Esilaba *et al*. (2021) low crop yield will persist even where soil moisture is adequate, as long as key yield-limiting nutrients such as nitrogen and phosphorous are deficient in the soil. This is because crops require adequate nutrients to grow, and healthy growing plants use more soil water thus increasing water use efficiency (i.e. crop production per unit water use) (Okeyo *et al*., 2014). At the same time the movement of nutrients to the plants roots zone requires a moist soil environment (Njeru *et al*., 2015).

To enhance increased soil nutrients uptake by crops requires adequate soil moisture to enable nutrient movement to underneath soil layers by movement of soil water content influenced by rainfall amount and distribution and also determined by the type of soil physical properties (Mwadalu and Mwangi, 2013; Moraru and Rusu, 2013). Therefore, soil water and nutrients play an essential for crop growth and development. The status can also alternate during seasons and at the end which determines the final crop yields due to their synergistic effects (Miriti *et al*., 2013). Different farmyard manure can also improve nutrient use efficiency from inorganic fertilizers and limit water stress-related crop growth penalties in water deficit conditions (Mugwe *et al*., 2007b; Okalebo *et al*., 2006). Thus, optimizing land productivity should aim at having ISFM technologies should be promoted to address agricultural production systems that address both soil moisture and soil fertility for climate resilient crop production systems (Mugwe and Oduor, 2021).

2.1.4 Cropping Patterns in Arid Areas of Central Kenya Highland

Sorghum comes second after maize in cereal food crop production by individual households. Sorghum is a drought-tolerant crop and is also able to thrive under water-logged conditions (Muui *et al*., 2013). The crops rainfall requirement in the range of 420 mm – 630 mm per annum. In Kenya, Sorghum is produced in semi-arid Eastern, Western, and Coastal regions.

Due to its climate resilience, many farmers in Kenya are finding sorghum production more attractive than maize. Sorghum features such as fast maturity, adaptability, and adaptable sorghum sowing dates, producers find sorghum ideal crop for SALs. The predominant farming system in the SALs consist of mixed farming where crops such as common bean, cowpeas, millet, sorghum and pigeon peas are grown side by side with livestock enterprises (Esilaba *et al.*, 2021). Most farmers practice mixed cropping on their farms, particularly inter-cropping cereals and legumes (Matusso *et al.*, 2012).

Where legumes/cereal Inter-cropping is involved, there is possibility of nitrogen transfer to the cereal (Njeru *et al*., 2014). The canopy of the crop will also maximize interception of radiation and reduce evaporation thus maximizing growth resources use efficiency (Kimani *et al*., 2007).

Maize and common bean production in mixed-livestock systems within semi-arid areas are projected to decrease in most regions in 2050 (Thornton *et al*., 2010). Farmers use mixed cropping as a way of not risking their production systems against unreliable weather, pest and diseases and accessing the benefits of legume–maize rotations in production systems (Ojiem *et al.,* 2014). This means soil moisture conservation in these areas is an important factor for increased crop production. This can be achieved probably through employing appropriate SWH techniques (Miriti *et al.,* 2013). Therefore, this study tested and compared the perception of farmers on these water conservations and ISFM on different cropping patterns in two study sites.

2.2 Fertilizer- Livestock and Crop Interaction

2.2.1 Soil Fertility Management - Using Organic Fertilizers for Crop Production

Livestock provide soil organic resources as waste product (Opala *et al*., 2015), as they graze on crop residue, unwanted crops and boundary vegetation (Bationo *et al.*, 2004; Fujisaki *et al*., 2018), thus recycling nutrients back to the soil. Free grazing makes it hard to recover nutrients from animal manure as nutrients are readily lost through runoff and volatilization. To evade this, livestock are placed in stalls (Lekasi *et al*., 2000; Adams *et al*., 2020). Use of cattle manure at 40 t ha^{-1} of kraal manure to fertilize crops was introduced by colonial agricultural officers throughout Africa, often at rates which a modern day smallholder farmers cannot afford (Opala *et al*., 2015). These amounts have been adjusted to mineral fertilizers equivalent to rate of 5 t ha^{-1} of farmyard manure (KARI, 2009). The available evidence suggest that based on the right quantity and quality of organic inputs it is possible to increase soil organic carbon (SOC) contents in the tropical soils (Laub *et al*., 2022). In addition, manure, green manure (for instance, from *Tithonia diversifolia*) exhibit rapid decomposition and thus an effective source of plant nutrients (Ndung'u *et al*., 2023; Mucheru-Muna et *al*. 2014). Additionally, deep rooted green manures remobilize soil nutrients from lower soil horizons to the upper surface for crop uptake (Hafifah *et al*., 2016).

2.2.2 Soil Fertility Management - Using Inorganic Fertilizers

Nitrogen and phosphorous fertilizers lost through soil erosion are estimated to cost global economies 34 and 80 billion US dollars year^{-1}, respectively (World Bank, 2020). According to Le *et al*. (2014), land degradation in key cereals production systems in Kenya costs ~270 million US dollars year^{-1}, about 1% of Kenyan gross domestic product. This large financial burden hinders efforts to restore soil fertility using inorganic fertilizers in smallholder farming system in Kenya (Oduor *et al*., 2023). Besides increasing crop yields, fertilizers also improve the nutritional concentration in crop residues that are partially used as animal feeds or incorporated to the soil as organic manure (Njeru *et al.,* 2014). For instance, phosphorous (P) fertilizers in leguminous crops can double biomass production and also crop yield per unit amount of P applied in the next cultivated crops (Mutuku *et al*., 2020). Similarly, Gebremichael *et al.* (2019) adds that starter N in legumes improves nodules and increases the available soil N to the subsequent cereal crop. Right time and place in the domain of 4R nutrient stewardship substantially enhances crop yields and nutrient use efficiency (Woomer *et al.*, 2010: Ngetich, 2012).

In another perspective, organic material for example sawdust and maize stover are placed in animal shelters for insulation and to collect animal urine for use as a bio-fertilizer (Lekasi, 2000). Animal shelters may be cast with concrete floor for ease of urine harvesting for use in the crop fields (Naudin *et al*., 2010). Chicken manure: consisting of droppings, uric acid, feed refusals are also another source of high quality manure (Ndung'u *et al.*, 2023). According to Njeru *et al*. (2013b), to guarantee high quality manure, the compost is piled together for proper decomposition before the onset of the cropping season and covered to reduce nutrient loss conserve nutrients. Thus, to optimize crop production, farmers should aim at having high quality manure production on-farm and recommended fertilizer application rates that address soil fertility improvement, soil moisture retention in central Kenya.

2.3 Integrated Soil Fertility Management (ISFM)

2.3.1 Soil Fertility Management

Integrated soil fertility management is adopted from Sanchez's (2009) work that emphasize on relying on biological processes by adopting seeds that improve soil health, promoting soil biological activities and nutrient cycling to reduce nutrients re-application and enhance nutrient use efficiency. Sanchez's work recognizes the advantage of incorporating essential organic inputs and mineral fertilizers. The available farmer organic resources were validated as crucial entry point for ISFM in smallholder farmers' fields (IFDC, 2012). Integrated soil fertility management has been defined in Vanlauwe *et al*. (2010) as the use of improved certified seeds and inorganic fertilizers targeting short-term productivity, combined with the application of organic resources to the soil.

Co-applying inorganic fertilizers and organic resources leads to more benefits than either inorganic alone being applied due to enhanced synergistic interactions effects among edaphic factors (Muindi *et al.*, 2016). The present conventional smallholder farmer practices are unsustainable (Kisaka *et al*., 2015). In this regard, transition phases from the conventional practice to optimized ISFM in the SALs of Kenya is necessary (Rewe *et al*., 2021). The African Fertilizer Summit (2006) highlighted the need to increase on-farm fertilizer application from the then 8 to 50 kg ha^{-1} in the next 9 years–after 2006 as a guideline for fertilizer use to fight food insecurity in SSA. The Virtual Fertilizer Research Center (VFRC) IFDC, 2012) provided funds to support the development and commercialization of new fertilizers and technologies that have supported Africa Fertilizer Summit 2006 goals.

2.4 Soil Water Harvesting (SWH) Technologies

2.4.1 In Situ Soil Water Harvesting

Soil water harvesting (SWH) is defined as harvesting of runoff water and catches the rain drops where they hit the ground (Grum *et al*., 2017). A main concern in dryland is to avoid runoff and catch the rain drops where they hit the ground. Water infiltrates and gets stored in the soil for crop uptake and ground water recharge. Runoff harvesting has proved to be an appropriate SWH method because it is just 15% of water in the terrestrial ecosystems that is used by crops (Taddele, 2015). These technologies are not commonly used in smallholder fields in SALs of Kenya, thus, these farmers miss out benefits such as increase of soil carbon, prevention of soil erosion control as well as nitrogen leaching (Hafifah *et al*., 2016). This remains a challenge in sorghum and cowpea systems in the SALs of Kenya. Ngetich *et al*. (2014b) observed increased crop yields and soil physical properties under Tied ridge system in Kenya. They have demonstrated to be efficient in reduction of total crop loss, thus a drought adaptation strategy.

The preparation of the upper layer of the soil to allow SWH is an important technique for adequate aeration of soil water infiltration and erosion control which increases crop production (Grum *et al*., 2017). However, literature suggests that water loss by evaporation and transpiration in cereals is directly proportional to their productivity (Ngetich *et al*., 2014a; Grum *et al*., 2017). SWH practices such as tied ridging capture rain drops then it infiltrates into the soil which make it available for crops (Okeyo *et al*., 2014). Studies have further indicated that SWH techniques have potential benefits for smallholder farmers (Olarinde *et al*., 2012). Overall, SWH in SALs shows promising potential benefits to smallholder farmers. However, the grey area is whether those benefits are immediate and tangible to encourage farmer's uptake of the technologies.

2.5 Cost Benefit Analysis on Various Agricultural Technologies

2.5.1 On-Farm Economic Return on Various Cropping Patterns

Intercropping is the most popular cropping system among smallholder farmers East Africa (Odendo *et al*., 2012). Maize and common bean are ranked 1st and 2nd most important staple food crops in Kenya and they are commonly intercropped (CIMMYT, 2003). Despite their pivotal role in Kenyans food security, their grain yields remain below attainable range. Such low yields are mainly caused by uncertified seeds, unbalanced fertilizer use and use of archaic agronomic practices (Opala *et al.,* 2015).

Intercropping of a cereal and legume in a cropping system has been reported to reduce individual crop yields resulting to low economic return especially in drier parts of Kenya (Karuma *et al*., 2016). The crop yield reduction in Inter-cropping a cereal and legume may be attributed by competition for growth resources (Kinyua *et al.*, 2023). There is a common practice by farmers Inter-cropping cowpea or groundnut by replacing common beans for food security by minimizing risk and maximization of land utilization and labour (Mucheru-Muna *et al.,* 2010). The challenge of decreased yields in Inter-cropped systems has driven the development of innovative Cropping patterns that utilize crop complementarity due to growth patterns, canopy structure and resource needs to achieve both high cereal and legume yields within an Intercropping system (Kinyua *et al.*, 2023). Farmers Intercropping cereals with legumes to improve soil fertility (Ondedo *et al.*, 2011), reduce fertilizer application, diversify their diet and income, utilize farm labor efficiently, and attain better yields (Dolijanović *et al.*, 2009). However, the cost-benefit analysis of soil water management practices on growing Inter-cropping of sorghum and cowpea is not well documented in dry and medium potential areas of Embu and Kirinyaga Counties in Kenya. Soil moisture conservation through tillage practices has been reported as a superior technique for addressing soil moisture deficits in rain-fed agriculture (Sibomana, 2016).

CHAPTER 3: METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location of the Study Sites

This research was undertaken in Mbeere South and Kirinyaga West Sub-counties of Embu and Kirinyaga Counties from 2011 to 2012. These study sites represent areas that may be classified as being under acute food, low poverty levels and undergoing livelihood crisis **(**Maina *et al*., 2012**)**. The Mbeere South study sites were selected to represent the drier parts of Embu county, while Kirinyaga represented the medium potential area of Kirinyaga County. The experimental site was located at Mariari girl's secondary school and Karima primary school in Embu and Kirinyaga Counties, respectively. The study trials were researcher managed. The local community was involved in learning and they were exposed to the technologies at physiological maturity stage by conducting farmer-field days.

The rainy seasons in the study sites are categorized into long rains which are received between March and June, and short rains between October and December (Jaetzold *et al*., 2007a). The two sites are classified as arid lands and occupying a total area of 2,821 km^2 southeastern part of Mt. Kenya (Figure 3.1). It lies between latitudes 0.91672°S and 0.47330°S, and between longitudes 37.47680°E and 37.91238°E, 800 meters above the sea level (Figure 3.1). The annual average rainfall in the area ranges from 700–900 mm, with mean annual temperature of 22°C–23°C. The dominant soils according to World Reference Base (WRB) are Ferralsols (Jaetzold *et al*., 2007a). According to Kenyan Agro-ecological zones, the area is categorized into Low Midland Zone IV and Lower Midland Zone V (Jaetzold *et al*., 2007a). In Mbeere South Sub-County, the study was carried out in agro-ecological zone (LM4). The rainfall data were recorded using a rain gauge located at Mariari Girls' Secondary School and the monthly averages were then calculated as shown (Figure 3.2).

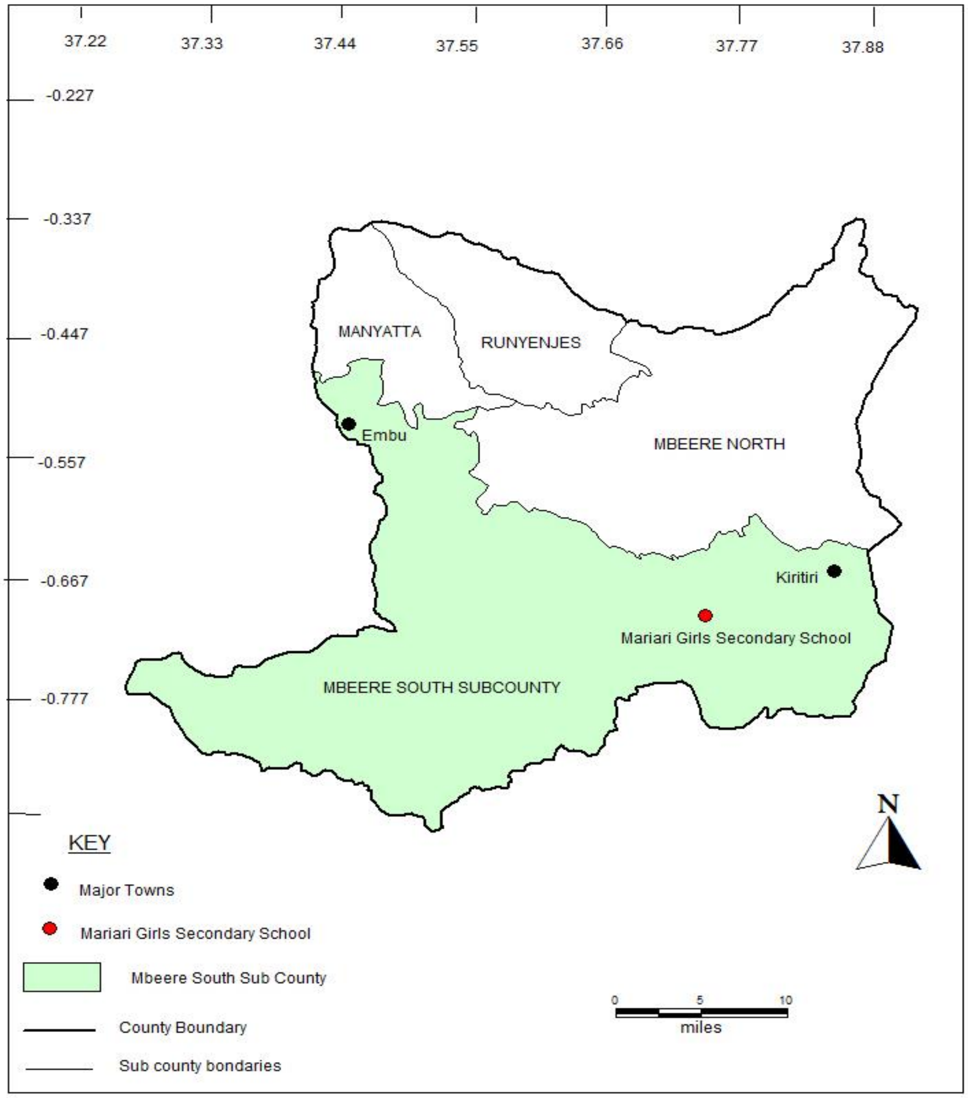

Figure 3.1: Map Showing Study Site in Mbeere South Sub-County (Source: Author 2025)

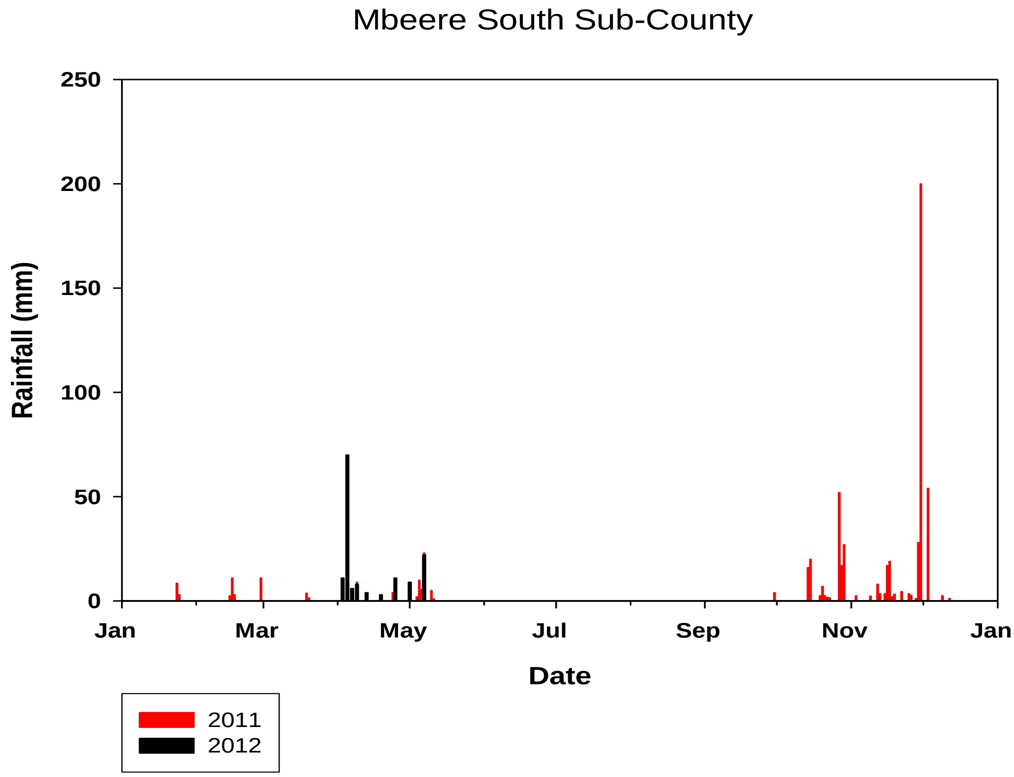

Figure 3.2: Rainfall distribution of LR 2011, 2012 and SR 2011 in Mbeere South Sub-County.

Kirinyaga West Sub-County study site is classified as medium potential area with declining potential covering an area of 1478.1 km^2 and lies along the southern slopes Mt. Kenya (Figure 3.3). The County lies between latitudes 0°1' and 0° 40'S and longitudes 37^o and 38'E, 1480–6800 metres above the sea level. The mean annual rainfall in Kirinyaga County ranges from 900–2700 mm, while 14° C and 30° C are the annual minimum and maximum temperature, respectively. The soil type is volcanic referred as Andisols are fertile soils that effectively retain nutrients and water, often containing volcanic debris and typically found in regions with above-average rainfall (Jaetzold *et al*., 2007b). In addition, Kirinyaga West sub-County covers eight agro-ecological zones (Jaetzold *et al*., 2007b; GoK, 2020). Particularly, this research was carried out in agro-ecological Zone Upper Midland IV. This is the area which is favourable for maize production as described by Jaetzold *et al*. (2007b). A rain gauge at Karima primary school was used to collect the rainfall data (Figure 3.4).

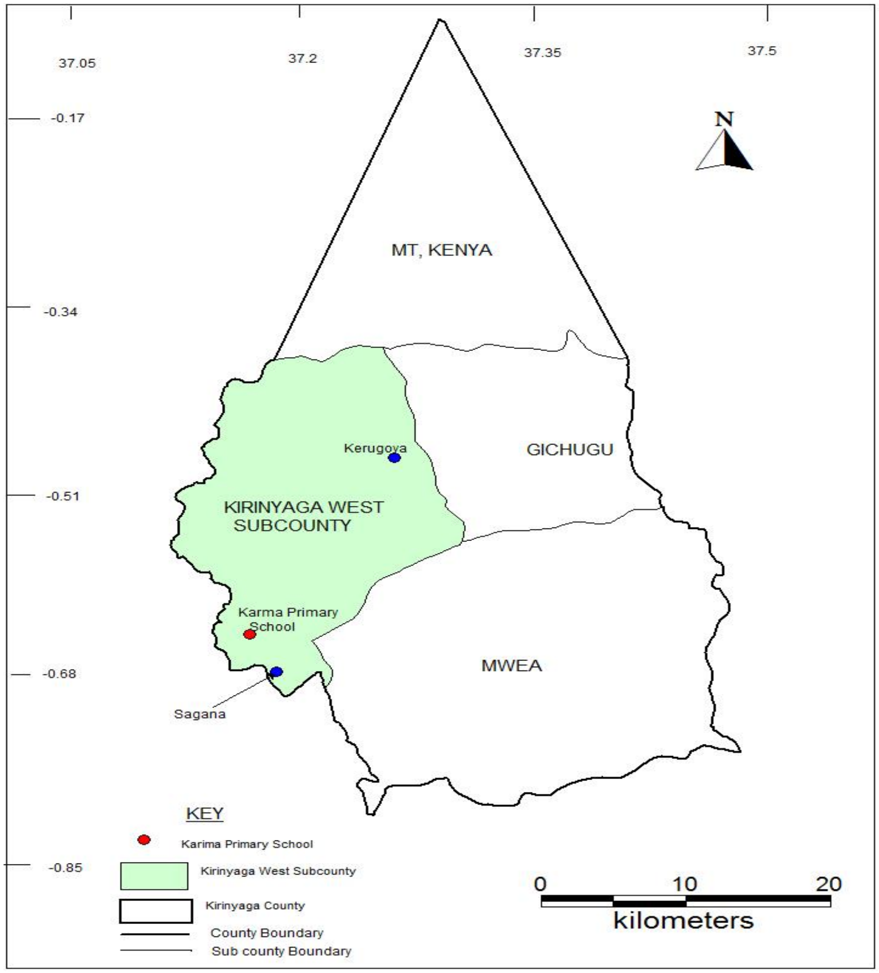

Figure 3.3: Map showing study site in Kirinyaga West Sub-County (Source: Author 2025)

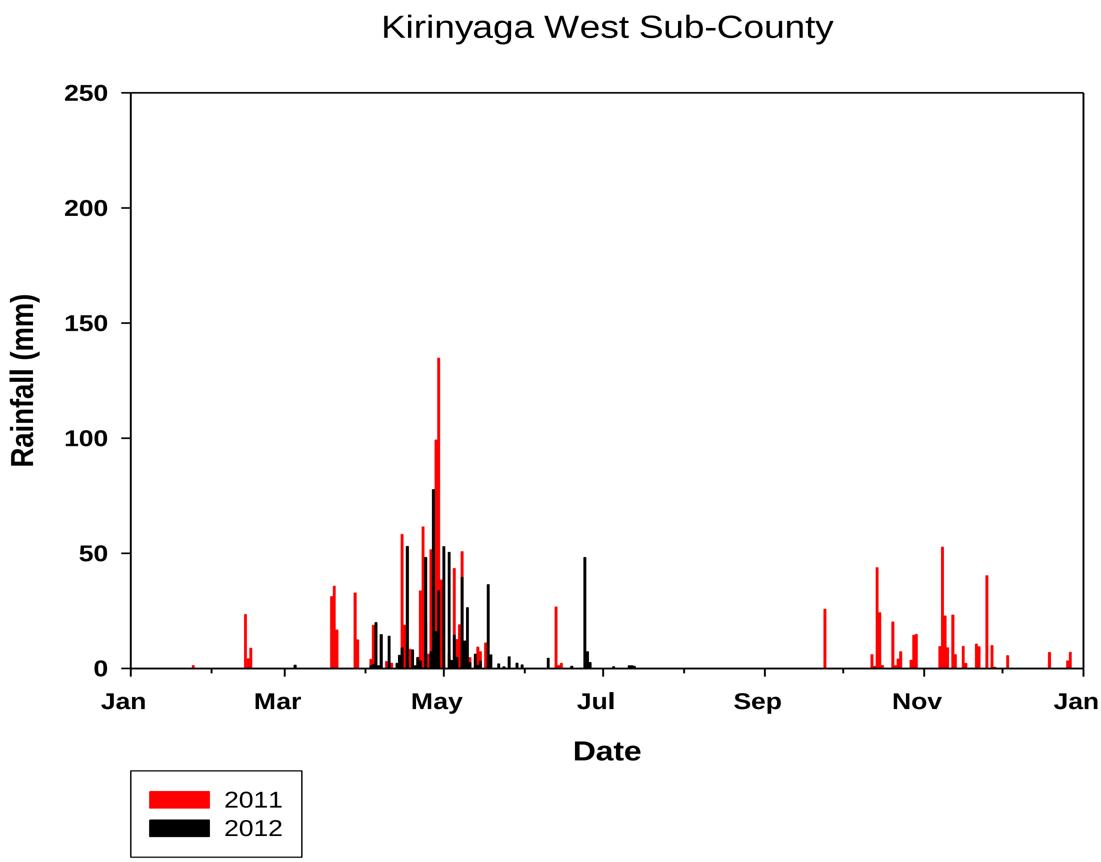

Figure 3.4: Rainfall distribution of LR 2011, 2012 and SR 2011 in Kirinyaga West Sub-County

3.1.2 Farming Systems

Maize, common bean, cowpeas and mung bean are the dominant crops in Mbeere South. Maize and common bean are mostly cultivated within the mixed-farming livelihood areas and maize cowpea, while mung bean is cultivated in the marginal mixed farming livelihood areas. According to Embu County statistics in 2020, maize provides 38% of food and 25% on-farm cash income within the Mixed farming livelihood areas and 50% food and 10 on-farm cash income in the marginal mixed farming livelihood areas. On the other hand in Kirinyaga-West Sub-County, subsistence and cash crops occupy >30% and ~20% of the crop land area under (KNBS, 2019). In Kirinyaga-West Sub-County, farmers practice subsistence (maize common bean and Irish potatoes), large-scale (avocado, rice, coffee, and tea) and mixed farming systems (e.g., livestock and coffee) according to County Government of Kirinyaga (2018).

3.1.3 Soil Type of Study Areas

The soil characterization data was collected at the beginning of the experiment where soil samples were collected at the depth of 0-20cm. The choice for the depth was chosen because this is the zone where most soil nutrients are concentrated and most of feeder roots most crops are concentrated. Soil types in the two areas varied in soil texture, sand, silt and clay. The soil texture (Table 3.1) is sandy loam and silty loams in Mbeere South and Kirinyaga West, respectively (Ryan *et al*., 2001). The soil pH ranged from strong acidic to moderately acidic in Karima and Mariari sites, respectively. The soil acidity in the region is due to leaching of exchangeable bases from the top layer of soil and their subsequent replacement with Al^{3+}.

Soil organic carbon and total N in both sites were above 1.5% and 0.12% which were low in Kirinyaga West and Mbeere South, respectively. Plant available P was high (31.48–52.8 mg kg^{-1}) with P considered to be adequate at the range of 13 to 22 ppm. This high plant-available P in the soils in the study sites could be attributed to regular application of phosphate fertilizers. The source of plant-available P is different from that of N because P cannot be fixed in the soil through biochemical processes (think of nitrogen fixation for N) but must be applied to the soil from an external resource. Therefore, it is crucial regularly re-apply P to maintain its levels to avoid its depletion in the soils, which can be detrimental to crop production.

Table 3.1: Baseline Soil Characterization of Study Sites

	Kirinyaga West Sub-County	Mbeere South Sub-County
Soil parameters	**Soil**	**Soil**
Sand (%)	12	60
Silt (%)	78	23
Clay (%)	10	17
Soil type classification	Silty loam	Sandy loam
pH water (1:2.5)	5.2	5.5
Total Nitrogen (%)	0.13	0.12
Total Phosphorous (%)	-	-
Total organic Carbon (%)	1.88	1.5
C:N ratio	14.5	12.5
P (mg kg^{-1})	52.8	31.48
K (mg kg^{-1})	445.3	334.9
Ca (mg kg^{-1})	1017.6	929.3
Mg (mg kg^{-1})	484.3	309.3
Cu (mg kg^{-1})	5.5	5.9
Zn (mg kg^{-1})	0.74	0.69
Fe (mg kg^{-1})	52.2	2.5
Mn (mg kg^{-1})	1729.5	1158.7

The analysis for manure (Table 3.2) used in both study sites indicated that pH water was 9.41, 9.24 and 9.31 during the LR 2011, SR 2012 and LR 2012 respectively. However, it had a total N, P and C of (1.70%, 1.65% and 1.69%), (0.49%, 0.45% and 0.47%) and (22.5%, 22.0% and 22.3%) during the LR 2011, SR 2012 and LR 2012, respectively. Ca, Mg and K of (0.88%, 0.76% and 0.84%), (0.48%, 0.43% and 0.46%) and (1.91%, 1.85% and 1.90%), during the same seasons respectively. It was applied in equivalent of 20 Kg N ha^{-1} and 40 Kg N ha^{-1} for half and optimal rates respectively, with a C:N ratio of 13.2, 13.3 and 13.2 which favours net soil mineralization.

Table 3.2: Total Mineral Concentration in the Manure Used For Planting during the 2011 LR, 2012 SR And 2012 LR in Both Study Sites

Manure parameters	pH water (1:2.5)	Total (%) N	Total (%) P	Total (%) C	Total (%) K	Total (%) Ca	Total (%) Mg	C:N ration
LR 2011	9.41	1.70	0.49	22.5	1.91	0.88	0.48	13.2
SR 2011	9.24	1.65	0.45	22.0	1.85	0.76	0.43	13.3

LR 2012	9.31	1.69	0.47	22.3	1.90	0.84	0.46	13.2

3.2 Experimental Design and Management

The study design was an experiment with treatments arranged in a factorial arrangement layout in Partially Balanced Incomplete Block Design (PBIBD). There were 3 factors namely 1. Soil water harvesting (SWH) techniques at 3 levels (i.e., Tied ridging, contour furrows and Farmers Practice), 2. Cropping patterns at two levels (Mono-cropping sorghum-Gadam, Sorghum and cowpea (M66) Inter-cropping and 3. Organic and inorganic fertilizer rates at 6 levels (Control, 40 kg P ha^{-1} + 40 kg N ha^{-1}, 40 kg P ha^{-1} + 20 kg N ha^{-1}, 40 kg P ha^{-1} + 40kg N ha^{-1} + Manure 5 t ha^{-1}, 40 kg P ha^{-1} + 20 kg N ha^{-1} + Manure 2.5 t ha^{-1} and manure 5 t ha^{-1}). This structure gave 36 treatment combinations (3 * 2* 6= 36). Each treatment was triplicated, giving a total number of 108 plots in each of the sites with a blanket application of P at 40 kg ha^{-1} (Table 3.3).

Table 3.3: Treatments Arrangement Structure for Mbeere South and Kirinyaga West Sub-Counties

Soil water harvesting (SWH) techniques (3 levels)	Cropping patterns (2 levels)	Organic and inorganic fertilizer rates (6 levels)
(i) Tied ridging (TR)	(i) Mono-cropping (sorghum alone)- Gadam	i. Control
(ii) Contour furrow (CF)		ii. 40 kg N ha^{-1} + 40 kg P ha^{-1} (optimal rate)
(iii) Farmers Practice (FP)	(ii) Inter-cropping (sorghum and cowpea)- M66	iii. 20 kg N ha^{-1} + 40 kg P ha^{-1} (half optimal rate)
		iv. 40 kg N ha^{-1} + 40 kg P ha^{-1} + Manure 5 t ha^{-1} (optimal rates)
		v. 20 kg N ha^{-1} + 40 kg P ha^{-1} + Manure 2.5 t ha^{-1} (half optimal rates)
		vi. Manure 5 t ha^{-1}

Land preparation was done manually to a 15 cm depth, and this represented farmers practice plots. Tied ridging and contour furrows were made manually since these were not yet mechanized. The furrows were made at spacing of 75 cm in the whole plots which represented contour furrows. Then for Tied ridging plots, the furrows were cross tied (sub-ridges joining big ridges were constructed at 100 cm intervals) to stop water movement within the furrow and make micro-check dams for catching rainwater and retaining it within the plot. The ridges and ties were 15 cm and 10 cm high, respectively. Fertilizer and Farm Yard Manure (FYM) application was done by banding along shallow furrows.

Dry planting and weed control were done based on the need to maintain clean plots during the season. NPK 23:23:0 and Triple Super Phosphate were spread along the shallow furrows and incorporated into the soil at sowing**.** Seeds were sowed in rows in 24 m^2 plots with a designed net plot of 225 cm × 200 cm at the center of the plot. Inter and intra row spacing between the sorghum pure stands was 75 cm by 20 cm, respectively. Same-row-planting for sorghum and cowpea was done in alternating planting holes but keeping planting hole-hole distance the same. Two to three weeks after emergence, sorghum and cowpea plants were thinned to one plant $hill^{-1}$.

3.2.1 Growth Parameters and Yields

In sorghum plots, plant heights, heads weight, stovers and grain yields were recorded while only dry grain and dry biomass yield were measured in cowpeas. The sorghum heights were recorded every two weeks from the day of planting (2WAP) and it was at this stage interval when Soil Water Content (SWC) was assessed during the season. Ten sorghum plants were randomly selected within the net plot area and their heights measured using a tape measure, See (Appendix I).

Harvesting of sorghum and cowpea was at physiological maturity in the net plot area (225 cm x 200 cm) in the centre of the plot obtained by leaving either 3 or 2 outermost rows on either plot's side or 100 cm on each row from both ends to reduce the edge effect. Total plants and the corresponding field fresh weights were also determined during the experimentation period. Samples and sub-sample fresh weights of grain pods and stovers were collected at harvesting. The samples were transported to laboratory for oven drying for the measurement of dry weights. Thereafter, threshing was done and the grain moisture content was adjusted to 13.5% in the final measurements.

Dry weights of the stovers were determined after oven-drying at 65° C to a constant weight. The dry weights of stovers (Biomass + Husks) and grains (Grain yields) after hand shelling were weighed, determined and weights extrapolated to reflect total biomass and crop yield in each treatment, respectively. These yields were expressed in tonnes/ha (which is equivalent to Mg ha^{-1}). Finally, Biomass plus Husks (t/ha) and grains yields (t/ha) were also calculated by combining them to give amount of Total Dry Matter (TDM).

3.2.2 Soil Physical and Chemical Properties

Soil was sampled from each plot at 0–20 cm depth using soil auger in the beginning prior to planting and at the end of the last cropping season. Five samples were taken from the plot by taking four samples in every direction from the plot mid-point. The soils were composited into a uniform sample. The composite samples were packed well and labelled before being transported to the laboratory for analysis. Soil texture was determined by the Bouyoucos Hydrometer method (Gee and Bauder, 1986), total organic carbon (Okalebo *et al*., 2002), total N (Anderson and Ingram, 1993) while pH of soil was measured by pH meter in a 1:2.5 soil-water ratio.

Exchangeable Calcium, Potassium and Magnesium were extracted by 1 molar NH_4OAC, then measurements taken by use of Atomic Absorption Spectrophotometer (AAS). For available phosphorus, the Bray P2 method followed by colorimetric determination was used. 1% Ethylenediaminetetraacetic acid (EDTA) was used to extract Zn, Cu, Mn, and Fe, then measurements taken by use of atomic absorption spectrophotometer (AAS).

3.2.3 Soil Moisture Content Measurement

Soil moisture contents were read by use of a portable diviner 2000 technique. This technique involves measuring SWC around the tube at 5 cm radius and taking measurements after every 10 cm interval to the bottom depth of the tube. Access tubes in the experiment had been mounted at the center of the plot by inserted polyvinyl chloride (PVC) tubes of 1.3 m length with a water tight lid at the bottom during 2011 long rains. A portion of 30 cm of the access tube was left above the soil surface and was also sealed to ensure water does not enter the tubes. Additional three tubes were also installed for calibration, and they were set alongside the experimental plots in a representative position. The moisture access tubes remained undisturbed to equilibrate and stabilize with the soils for a whole season until SR 2011 when soil moisture monitoring begun until LR 2012 (Plate 1).

Plate 1: Soil Moisture Content Measurement at Different Stages of Cropping System Using Diviner 2000.

A calibration pit was dug near the access tubes and samples of soil obtained in intact 100 cm^3 cores at the depth interval of 10 cm at which Diviner readings were recorded. The dry bulk density was determined by gravimetric method (appendix II). Soil water content measurements were taken fortnightly starting from 2 weeks after planting time until just before harvest of sorghum every season. The SWC was measured at different stages of growing season at 2 Weeks after Planting (WAP), 4WAP, 6WAP, 8WAP, 10WAP, 12WAP, 14WAP and 16WAP up to a depth of 0.8 m depending on the length of the season in Mbeere South and Kirinyaga West Sub-Counties.

3.2.4 Farmers Evaluation Knowledge on Treatment Performance Criteria

A structured evaluation questionnaire (Appendix III) was administered in the two study sites. This was used to evaluate farmer’s perception of different treatments performances as a result of effect of SWH methods and ISFM technologies on sorghum and cowpea performances every season. The evaluation was done at the end of the long rains of 2011, 2012 and short rain of 2011 season, during farmer’s field day. The farmers rating of each plot was done using either as good, fair or poor based on their own judgement on how crops performed. Finally, their rating was compared with biophysical yield data that was collected in each treatment. The local farmers 351 and 345 farmers participated in evaluation of the exponential treatments in Mbeere South and Kirinyaga West Sub-Counties, respectively. Additionally, farmers were requested to rate treatments in the study (i.e., 108 plots in both study sites). Farmers also indicated the on-farm SWH methods and soil fertility amendment practices they have implemented in their farms.

3.2.5 Economic Data

The financial returns of combinations of SWH, cropping patterns and soil fertility management practices at different levels were estimated following the partial budget analysis protocol proposed in CIMMYT (2003). The Cost Benefits Analysis was carried out to calculate the cost for production and profitability associated with each treatment. The cost for production parameters were collected throughout the 3 seasons in 2 study sites; the cost for fertilizer, certified seeds and manure was based on local agro-vet prices in each study sites. Other related costs for labour data such as land preparation, construction of SWH structures, fertilizer application, planting, thinning and crop yields harvesting was collected by recording the time taken from a minimum of 3 individuals from different gender undertaking the activities (Table 3.4) according to CIMMYT (1988) guidelines.

Table 3.4: Variables Used in Calculation of Financial Returns

Parameter price	Mbeere South Sub-County (USD)			Kirinyaga West Sub-County (USD)		
	LR 2011	**SR 2011**	**LR 2012**	**LR 2011**	**SR 2011**	**LR 2012**
TSP (0-46-0) fertilizer (USD per kg P)	1.24	1.24	1.3	1.24	1.24	1.3
NPK (23-23-0) fertilizer (USD per kg N)	0.79	0.79	0.83	0.79	0.79	0.83
Manure (USD per ton)	11.28	11.28	11.84	11.28	11.28	11.84
Sorghum seeds (USD per kg)	1.41	1.41	1.48	1.41	1.41	1.48
Cowpea seeds (USD per kg)	1.69	1.69	1.78	1.69	1.69	1.78
Cost (USD per day)	3.38	3.38	3.55	3.38	3.38	3.55
Sorghum grains (USD per kg)	0.56	0.34	0.47	0.62	0.34	0.53
Cowpea grains (USD per kg)	0.62	0.62	0.89	0.96	0.68	0.95
Sorghum stovers (USD per ton)	67.67	56.39	65.1	67.67	56.39	71.01
Cowpea stovers (USD per ton)	33.83	22.56	35.51	39.47	22.56	35.51

Note: Exchange rate 88.69 Ksh = 1 USD year 2011, Exchange rate 84.49 Ksh = 1 USD year 2012

The cost for net return was collected from market prices given the amount of sorghum and cowpea yields from each treatment for 3 seasons. The net benefit, benefit-cost ratio (BCR) (returns per shilling invested) and return to labour was used as economic tool in accessing treatments profitability and they were determined using the following Equation 1-3;

NB = (GB - TCP) ………………………………………….Equation 1

BCR = (NB/TCP)………………………..…………….. .Equation 2

RTL = {(GB –COI)}/COL…………………….……………Equation 3

Where, NB = Net benefits; GB = gross benefits; TCP = Total costs of production; BCR = benefits cost ratio; RTL = Return to labour; COI= cost of inputs COL= Cost of labour.

3.3 Data Analysis

Crop growth parameters, yields, soil properties and economic returns data were analysed by analysis of variance. Least significant different (LSD) 5% alpha level was the post-hoc mean separation technique applied in this study. Exploration analyses were conducted to establish any interaction effects among factors at different levels were significantly different. Correlation and regression were used establish if any statistical association exist between variables. The data from soil chemical parameters were subjected to *student t*-test at 95% confidence interval. Data from the farmer's treatment rating were coded into SPSS version 17 and analyzed descriptively. Mean scores and sorghum grain yields data were computed to get the overall biophysical and farmers rank for each treatment. The test for correlation levels between biophysical data (actual sorghum yields) and farmers ranking mean scores was conducted. Pearson's rank correlation analysis was used to correlate farmer's age and education level on treatment rating at 95% confidence interval.

CHAPTER 4: RESULTS

4.1 Soil Water Harvesting Techniques, Integrated Soil Fertility Management and Cropping Patterns Effect on Sorghum and Cowpea Yields

4.1.1 Treatment Effects of Sorghum Height in Mbeere South Sub-County

The study was conducted during LR 2011, 2012 and SR 2011 seasons in Mbeere South Sub-County, Embu County. In the study site, there were no significant differences recorded within season except from treatment with tallest crops and controls. The shortest sorghum height (cm) was recorded during the LR 2011 season as compared to SR 2011 and LR 2012 seasons (Table 4.1). The sorghum height during the LR 2011 season ranged from 41.6 to 63.6 cm, while in SR 2011 and LR 2012 it ranged from 102.1 to 181.3 cm and 101.8 to 127.1 cm, respectively. Treatments means did not differ significantly during the LR 2011 and LR 2012 seasons (p>0.05), but treatments with the tallest plants differed significantly from the rest during the seasons. Data further showed that there were significant interaction effects (p=0.0531) between SWH methods and cropping patterns on sorghum height during the short rains of 2011. Soil water harvesting techniques (p=0.051), cropping patterns (p=0.00) and soil fertility options p=0.0314), significantly affected sorghum height (cm) during the SR 2011 season. SWH techniques consistently demonstrated a significant effect (p=0.0001) on sorghum heights during the LR 2012 season.

Table 4.1: Sorghum Height (Cm) in Various Treatments at Mariari Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

Soil Water Harvesting	Cropping patterns	Soil fertility amendment practices	Sorghum height (cm) LR 2011	Sorghum height (cm) SR 2011	Sorghum height (cm) LR 2012
Tied ridging	Intercropping	20N+40P	63.6a	137.5bc	118ab
Tied ridging	Intercropping	20N+40P+M2.5	51.4ab	181.3a	116.1ab
Tied ridging	Intercropping	40N+40P	53.1ab	133.1bc	121.4ab
Tied ridging	Intercropping	40N+40P+M5	51.7ab	124.5bc	122ab
Tied ridging	Intercropping	Control	44.1b	105.6c	101.8b
Tied ridging	Intercropping	M5	51.6ab	132.5bc	123.9ab
Tied ridging	Monocropping	20N+40P	52.2ab	127.7bc	127.1a
Tied ridging	Monocropping	20N+40P+M2.5	53.7ab	124.5bc	115.6ab
Tied ridging	Monocropping	40N+40P	48.8ab	126.9bc	120.4ab
Tied ridging	Monocropping	40N+40P+M5	58.4ab	126.4bc	120.5ab
Tied ridging	Monocropping	Control	45.2b	104.1c	104.7b
Tied ridging	Monocropping	M5	53.6ab	130.3bc	118ab
Contour furrow	Intercropping	20N+40P	50.4ab	130.2bc	111.4b
Contour furrow	Intercropping	20N+40P+M2.5	63.4ab	124.2bc	119.9ab
Contour furrow	Intercropping	40N+40P	50.9ab	123.1bc	114.8ab
Contour furrow	Intercropping	40N+40P+M5	47.7ab	120.4c	120.2ab
Contour furrow	Intercropping	Control	44.1b	108.9c	105.2b
Contour furrow	Intercropping	M5	51.3ab	131.7bc	111.1b
Contour furrow	Monocropping	20N+40P	46.8ab	128.3bc	119.1ab
Contour furrow	Monocropping	20N+40P+M2.5	51.4ab	119.8c	120.4ab
Contour furrow	Monocropping	40N+40P	54.7ab	129bc	119.8ab
Contour furrow	Monocropping	40N+40P+M5	56.1ab	121.7bc	111.4b
Contour furrow	Monocropping	Control	43.8b	106.5c	103.2b
Contour furrow	Monocropping	M5	53.6ab	118.4c	112.7b
Farmers Practice	Intercropping	20N+40P	50.4ab	131.7bc	105.7b
Farmers Practice	Intercropping	20N+40P+M2.5	54ab	138.3bc	109.7b
Farmers Practice	Intercropping	40N+40P	52.7ab	144.3b	113.1b
Farmers Practice	Intercropping	40N+40P+M5	48.3ab	131.9bc	109.6b
Farmers Practice	Intercropping	Control	41.6b	108.1c	105.5b
Farmers Practice	Intercropping	M5	61.7ab	127.7bc	104.2b
Farmers Practice	Monocropping	20N+40P	57.5ab	131bc	105.3b
Farmers Practice	Monocropping	20N+40P+M2.5	54.3ab	126.8bc	111.2b
Farmers Practice	Monocropping	40N+40P	49.3ab	126.8bc	104.5b
Farmers Practice	Monocropping	40N+40P+M5	46.6ab	123.7bc	113.4b
Farmers Practice	Monocropping	Control	45.1b	102.1c	104.8b
Farmers Practice	Monocropping	M5	48ab	112.6c	110.4b
CV (%)			10.2	9.7	5.97
$LSD_{(0.05)}$			12.19	23.18	12.69

SWH	0.724	0.051	0.0001
Cropping patterns	0.5153	0.001	0.126
Fertility management	0.4579	0.0314	0.9733
SWH*cropping patterns	0.887	0.0531	0.5766
SWH*Fertility management	0.2525	0.2249	0.4503
Cropping patterns*Fertility management	0.1994	0.4813	0.2408
SWH*Cropping patterns*Fertility management	0.0896	0.6036	0.2445

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea

The tallest sorghum plants (63.6 cm and 127.1 cm) were observed in Tied Ridged Intercropping and mono-cropping crop receiving 20N+40P during the long rains of 2011 and long rains 2012 seasons, in that order. Among the seasons, the tallest sorghum (181.3 cm) was recorded in the same SWH methods under Inter-cropping system with soil fertility management of 20N+40P+M2.5 during the SR 2011 season. These were significantly different ($p<0.05$) from their respective treatments regarded as experiment "controls" which recorded <45.2 cm, <105.5 and <108.9 cm during long rains of 2011 and 2012 and short rains of 2011, respectively. During LR 2012, the shortest crop heights were recorded in Farmers Practice, and they were significantly different from other SWH methods. Generally, the shortest sorghum heights were recorded in all the treatments regarded as experiment "controls" in all the SWH methods but in different categories of Cropping patterns in 3 seasons.

4.1.2 Treatment Effects of Sorghum Heights in Kirinyaga West Sub-County

The sudy was conducted during LR 2011, 2012 and SR 2011 seasons in Kirinyaga West Sub-County, Kirinyaga County. In the study site, there were no significant differences recorded within season expect from treatment with tallest crops and controls. SWH*Cropping patterns*soil fertility amendments interactions affected sorghum height significantly (p=0.0001) in SR 2011 but no interactions in LR 2011 and 2012. There was also a two-way interaction effect (p=0.01) of SWH*soil fertility options on sorghum heights during the SR 2011 season. There was also a two-way interaction effect (p=0.01) of SWH*soil fertility options on sorghum heights in SR 2011. However, the interactions effects were not significant (p>0.05) on sorghum heights on the other levels of interaction during the 3 seasons. SWH methods and cropping patterns showed significant effect (p=0.0052 and p=0.0065), respectively, on sorghum height in SR 2011, but soil fertility options did not. However, soil fertility options affected sorghum highly significantly (p=0.001) in LR 2011 (Table 4.2).

Table 4.2: Sorghum Height (Cm) in Various Treatments at Karima Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

SWH	**Cropping system**	**Soil fertility amendment practices**	**Sorghum height (cm) LR 2011**	**Sorghum height (cm) SR 2011**	**Sorghum height (cm) LR 2012**
Tied ridging	Intercropping	20N+40P	156.0a	132.8ab	155.5ab
Tied ridging	Intercropping	20N+40P+M2.5	113.78ab	119.7bc	159.5a
Tied ridging	Intercropping	40N+40P	76.67b	137.2ab	134.6ab
Tied ridging	Intercropping	40N+40P+M5	92.85b	135.8ab	131.8ab
Tied ridging	Intercropping	Control	56.63b	80.7c	102.6b
Tied ridging	Intercropping	M5	76.18b	152.3ab	136.4ab
Tied ridging	Monocropping	20N+40P	85.75b	160.1a	134.9ab
Tied ridging	Monocropping	20N+40P+M2.5	75.4b	87.4c	131ab
Tied ridging	Monocropping	40N+40P	102.33b	99.9bc	128.8ab
Tied ridging	Monocropping	40N+40P+M5	115.41ab	130.7ab	146.2ab
Tied ridging	Monocropping	Control	58.38b	81c	107.9b
Tied ridging	Monocropping	M5	93.55b	118.2bc	136ab
Contour furrow	Intercropping	20N+40P	86.4b	95.3bc	132ab
Contour furrow	Intercropping	20N+40P+M2.5	87.4b	131.9ab	133.6ab
Contour furrow	Intercropping	40N+40P	141ab	139.9ab	138.6ab
Contour furrow	Intercropping	40N+40P+M5	97.1b	123.1b	104.4b
Contour furrow	Intercropping	Control	63.4b	84.1c	102.4b
Contour furrow	Intercropping	M5	84b	143.1ab	115b
Contour furrow	Monocropping	20N+40P	150.7ab	117.3bc	148ab
Contour furrow	Monocropping	20N+40P+M2.5	112.8ab	119.4bc	133.4ab
Contour furrow	Monocropping	40N+40P	87.7b	139.8ab	135.9ab
Contour furrow	Monocropping	40N+40P+M5	91.5b	105.1bc	129.7ab
Contour furrow	Monocropping	Control	61.5b	87.7bc	115.5b
Contour furrow	Monocropping	M5	61.6b	110bc	125.4b
Farmers Practice	Intercropping	20N+40P	82.7b	133.6ab	135.3ab
Farmers Practice	Intercropping	20N+40P+M2.5	93.7b	119.5bc	132ab
Farmers Practice	Intercropping	40N+40P	95.3b	112.1bc	125.1b
Farmers Practice	Intercropping	40N+40P+M5	79.07b	117.7bc	141ab
Farmers Practice	Intercropping	Control	74.5b	77.7c	116.5b
Farmers Practice	Intercropping	M5	97.9b	92.7bc	146ab
Farmers Practice	Monocropping	20N+40P	87.87b	98bc	133ab
Farmers Practice	Monocropping	20N+40P+M2.5	103.31b	91.9bc	143.3ab
Farmers Practice	Monocropping	40N+40P	99.13b	125.9ab	127.1ab
Farmers Practice	Monocropping	40N+40P+M5	102.36b	112.8bc	149.7ab
Farmers Practice	Monocropping	Control	65.65b	73c	113.4b

Farmers Practice	Monocropping	M5	73.18b	115.3bc	135.8ab
CV (%)			13.94	11.7	10.65
LSD $_{(0.05)}$			51.47	35.55	33.68
SWH			0.651	0.0052	0.531
Cropping patterns			0.628	0.0065	0.971
Fertility management			0.001	0.37	0.056
SWH*cropping patterns			0.315	0.822	0.959
SWH*Fertility management			0.225	0.01	0.801
Cropping patterns*Fertility management			0.436	0.074	0.951
SWH*Cropping patterns*Fertility management			0.061	0.0001	0.122

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

The tallest sorghum (156.0–160.1 cm) were recorded under Tied ridging during the three cropping seasons (Table 4.2) while shortest sorghum plants were recorded in all the treatments regarded as “controls” in all the SWH methods but in different categories of Cropping patterns.

4.1.3 Treatment Effects of Sorghum and Cowpea Grain Yields in Mbeere South Sub-County

Comparative sorghum and cowpea yield during the three seasons indicated that there was better crop performance during the SR 2011 and LR 2012 seasons as compared to the LR 2011 season which was the worst season (Table 4.3). Sorghum yields recorded was 0.21–1.44 t ha^{-1} in LR 2011, 0.10–3.50 t ha^{-1} in SR 2011 and 0.50–3.80 t ha^{-1} in LR 2012. There was no data reported for cowpea grain yields in LR 2011 due to failed rains (Figure 3.2).

Three way interactions effect between SWH*cropping system*soil fertility options on sorghum grain yields was significant (p=0.0396) during LR 2012 only. SWH*soil fertility options had significantly interacted (p=0.0027, p=0.0008 and p=0.0057) and affected sorghum grain yields during long rains of 2011 and 2012, and short rains of 2011, in that order. During the three cropping seasons, the effects of SWH methods on sorghum grain yields differed significantly (p=0.002, p=0.0003 and p=0.0005), respectively, in LR 2011, SR 2011 and LR 2012. At the same time soil fertility options had significant effects (p=0.00) on sorghum grain yields during the three cropping seasons. In SR 2011 and LR 2012, soil fertility options also produced significant effects (p=0.0047 and p=0.0024) on cowpea grain yields, respectively (Table 4.3).

Table 4.3: Sorghum and Cowpea Grain Yields in Various Treatments at Mariari Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

Soil Water Harvesting	Cropping patterns	Soil fertility amendment practices	Crop yields (t ha^{-1})				
			Sorghum			Cowpeas	
			LR 2011	SR 2011	LR 2012	SR 2011	LR 2012
Tied ridging	Intercropping	20N+40P	1.40ab	2.70ab	2.60bc	0.45b	0.9ab
Tied ridging	Intercropping	20N+40P+M2.5	1.33b	3.50a	3.00ab	1.01ab	0.77ab
Tied ridging	Intercropping	40N+40P	1.27bc	2.10b	2.20bc	0.75ab	0.59ab
Tied ridging	Intercropping	40N+40P+M5	1.32bc	2.70ab	2.90ab	0.69ab	0.96a
Tied ridging	Intercropping	Control	0.21d	1.10c	0.50c	0.21b	0.06b
Tied ridging	Intercropping	M5	1.22bc	2.00b	1.50c	0.75ab	0.45ab
Tied ridging	Monocropping	20N+40P	1.26bc	2.00b	2.00bc	.	.
Tied ridging	Monocropping	20N+40P+M2.5	1.44a	3.00ab	3.80a	.	.
Tied ridging	Monocropping	40N+40P	1.29bc	2.80ab	2.00bc	.	.
Tied ridging	Monocropping	40N+40P+M5	1.44a	2.00b	2.30bc	.	.
Tied ridging	Monocropping	Control	0.24d	1.10c	0.90c	.	.
Tied ridging	Monocropping	M5	1.34ab	2.30b	1.90bc	.	.
Contour furrow	Intercropping	20N+40P	1.26bc	2.50b	1.80bc	0.87ab	0.6ab
Contour furrow	Intercropping	20N+40P+M2.5	1.34ab	2.40b	1.70bc	1.3a	0.66ab
Contour furrow	Intercropping	40N+40P	1.28bc	2.80ab	2.20bc	0.83ab	0.6ab
Contour furrow	Intercropping	40N+40P+M5	1.31bc	2.30b	1.70bc	0.7ab	0.73ab
Contour furrow	Intercropping	Control	0.21d	1.00c	0.90c	0.42b	0.22b
Contour furrow	Intercropping	M5	1.32bc	2.50b	1.70bc	1.09ab	0.57ab
Contour furrow	Monocropping	20N+40P	1.32bc	2.00b	2.70bc	.	.
Contour furrow	Monocropping	20N+40P+M2.5	1.29bc	2.70ab	2.40bc	.	.
Contour furrow	Monocropping	40N+40P	1.25bc	2.80ab	1.90bc	.	.
Contour furrow	Monocropping	40N+40P+M5	1.29bc	2.40b	1.40c	.	.
Contour furrow	Monocropping	Control	0.26d	0.50c	0.80c	.	.
Contour furrow	Monocropping	M5	1.24bc	2.50b	1.80bc	.	.
Farmers Practice	Intercropping	20N+40P	1.33b	2.40b	1.30c	0.7ab	0.48ab
Farmers Practice	Intercropping	20N+40P+M2.5	1.28bc	2.30b	1.80bc	0.67b	0.74ab
Farmers Practice	Intercropping	40N+40P	1.31bc	2.60ab	1.30c	0.75ab	0.58ab
Farmers Practice	Intercropping	40N+40P+M5	1.29bc	2.60ab	1.90bc	0.93ab	0.13b
Farmers Practice	Intercropping	Control	0.23d	0.10c	0.60c	0.19b	0.08b
Farmers Practice	Intercropping	M5	1.23bc	2.30b	1.70bc	0.86ab	0.63ab
Farmers Practice	Monocropping	20N+40P	1.35ab	2.30b	2.20bc	.	.

Farmers Practice	Monocropping	20N+40P+M2.5	1.26bc	2.10b	1.80bc	.	.
Farmers Practice	Monocropping	40N+40P	1.25bc	2.70ab	1.70bc	.	.
Farmers Practice	Monocropping	40N+40P+M5	1.30bc	2.30b	1.20c	.	.
Farmers Practice	Monocropping	Control	0.24d	0.60c	0.70c	.	.
Farmers Practice	Monocropping	M5	1.28bc	2.90ab	1.50c	.	.
CV (%)			13.3	12.4	10.9	11.0	10.5
$LSD_{(0.05)}$			0.107	0.933	1.08	0.622	0.537
SWH			0.002	0.0003	0.0005	0.5736	0.7309
Cropping pattern			0.423	0.5719	0.447	.	.
Fertility management			0.0003	0.0001	0.0001	0.0047	0.0024
SWH*cropping pattern			0.638	0.9604	0.9285	.	
SWH*Fertility management			0.0027	0.0057	0.0008	0.3155	0.8484
Cropping pattern*Fertility management			0.7527	0.0654	0.2508	.	.
SWH*Cropping pattern*Fertility management			6954	0.6019	0.0396	.	.

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

The treatments with the highest sorghum and cowpea yields significantly differed ($p<0.05$) from the least producers, i.e., the “control group” during the entire experimental period. The highest sorghum grain yields (1.44 t ha^{-1}, 3.50 and 3.80 t ha^{-1}) were recorded under Tied ridging in LR 2011, SR 2011 and LR 2012, respectively. While the best cowpea grain yields (1.3 and 0.96 t ha^{-1}) were recorded in treatments under Contour Furrows-Intercropping at 20N+40P+M2.5 and tied ridging-mono-cropping at 40N+40P+M5 during the SR 2011 and LR 2012 seasons, respectively. During LR 2011, SR 2011 and LR 2012, reported sorghum grain yields were 0.26 t ha^{-1}, 0.9 and 1.10 t ha^{-1}, respectively in the control treatment. On the other hand, cowpea yields in SR 2011 and LR 2012 were < 0.67 t ha^{-}1 and 0.22 t ha^{-1}, respectively.

4.1.4 Treatment Effects on Sorghum and Cowpea Grain Yields in Kirinyaga West Sub-County

The yields of sorghum and cowpea varied over the three seasons; i.e., >SR 2011>LR 2012 >LR 2011. Generally, grain yields increased with time from the 1st to the 3rd season in this study. However, SWH methods did not improve sorghum (p=0.0714, p=0.2018 and p=0.4902) and cowpea (p=0.1663, p=0.8756 and p=0.7856) grain yields during the LR 2011, SR 2011 and LR 2012, respectively. Similarly, cowpea seed yields remained statistically similar across the treatments (p>0.05) except from those with the highest yields during the LR 2011, 2012 and SR 2011 seasons, respectively (Table 4.4).

Statistically significant interaction effects of SWH* soil fertility options on cowpea production (p=0.0229) during the SR 2011 were observed. While all other factors did not show statistically interactions during the three cropping seasons. Cropping patterns' effects on sorghum grain yields during the LR 2011 and LR 2012 seasons were statistically significant (p=0.0024 and p=0.0.0048) but not in SR 2011 (p=0.0589). Soil fertility management options had significant effects (p<0.0001, p<0.0001 and p<0.0001) and (p=0.0434, p=0.0131 and p=0.0.0032) on sorghum and cowpea seed yields in LR 2011, SR 2011, and LR 2012, respectively (Table 4.4).

Table 4.4: Sorghum and Cowpea Grain Yields in Various Treatments at Karima Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

Soil Water Harvesting	Cropping patterns	Soil fertility amendment practices	Sorghum yields (t/ha)			Cowpea yields (t/ha)		
			LR 2011	SR 2011	LR 2012	LR 2011	SR 2011	LR 2012
Tied ridging	Intercropping	20N+40P	0.3c	1.7bc	2.9bc	0.22ab	0.84ab	1.36ab
Tied ridging	Intercropping	20N+40P+M2.5	0.5bc	2.6ab	3.4bc	0.19ab	0.86ab	1.79ab
Tied ridging	Intercropping	40N+40P	0.2c	1.7bc	2.1cd	0.19ab	1.57a	1.84ab
Tied ridging	Intercropping	40N+40P+M5	0.6bc	1.7bc	2.5c	0.2ab	1.18ab	1.46ab
Tied ridging	Intercropping	Control	0.1c	0.2c	0.4d	0.04b	0.54b	0.48b
Tied ridging	Intercropping	M5	0.1c	2.4ab	2cd	0.13b	0.85ab	0.97b
Tied ridging	Monocropping	20N+40P	0.5bc	2b	2.1cd	.	.	.
Tied ridging	Monocropping	20N+40P+M2.5	1.8a	3.5a	5.6a	.	.	.
Tied ridging	Monocropping	40N+40P	0.5bc	2.7ab	3.1bc	.	.	.
Tied ridging	Monocropping	40N+40P+M5	0.8bc	2.9ab	3bc	.	.	.
Tied ridging	Monocropping	Control	0.1c	0.6c	1.2d	.	.	.
Tied ridging	Monocropping	M5	0.3c	2.1b	2.4c	.	.	.
Contour furrow	Intercropping	20N+40P	0.3c	2.1b	2.1cd	0.06b	0.94ab	1.18ab
Contour furrow	Intercropping	20N+40P+M2.5	0.4bc	2.6ab	1.9cd	0.14b	1.34ab	1.67ab
Contour furrow	Intercropping	40N+40P	0.1c	1.8b	2.6c	0.13b	1.28ab	1.54ab
Contour furrow	Intercropping	40N+40P+M5	0.7bc	2b	3.1bc	0.2ab	1.53ab	1.9a
Contour furrow	Intercropping	Control	0.1c	0.5c	0.5d	0.07b	0.22b	0.48b
Contour furrow	Intercropping	M5	0.1c	1.4bc	1.9cd	0.17ab	1.13ab	1.55ab
Contour furrow	Monocropping	20N+40P	0.5bc	2.6ab	3bc	.	.	.
Contour furrow	Monocropping	20N+40P+M2.5	0.9bc	2.7ab	2.8bc	.	.	.
Contour furrow	Monocropping	40N+40P	0.1c	2.3b	2cd	.	.	.
Contour furrow	Monocropping	40N+40P+M5	0.6bc	1.6bc	2.4c	.	.	.
Contour furrow	Monocropping	Control	0.1c	1.2bc	1.2d	.	.	.
Contour furrow	Monocropping	M5	0.3c	1.7bc	1.6cd	.	.	.
Farmers Practice	Intercropping	20N+40P	0.2c	1.5bc	2cd	0.09b	1.05ab	1.41ab
Farmers Practice	Intercropping	20N+40P+M2.5	0.8bc	2.1b	2.5c	0.33a	1.45ab	1.35ab
Farmers Practice	Intercropping	40N+40P	0.9bc	1.8b	2.5c	0.13b	1.33ab	1.79ab
Farmers Practice	Intercropping	40N+40P+M5	0.5bc	2.4ab	3.8b	0.31ab	1.09ab	1.46ab
Farmers Practice	Intercropping	Control	0c	0.3c	0.7d	0.14b	0.31b	0.78b
Farmers Practice	Intercropping	M5	0.5bc	2.2b	2.4c	0.19ab	1.13ab	1.91a
Farmers Practice	Monocropping	20N+40P	0.3c	1.6bc	2.4c	.	.	.
Farmers Practice	Monocropping	20N+40P+M2.5	0.9bc	1.9b	3.2bc	.	.	.
Farmers Practice	Monocropping	40N+40P	1b	2.4ab	1.7cd	.	.	.
Farmers Practice	Monocropping	40N+40P+M5	1.2ab	1.7bc	3.5bc	.	.	.
Farmers Practice	Monocropping	Control	0c	0.5c	0.8d	.	.	.
Farmers Practice	Monocropping	M5	0.1c	1.9b	1.8cd	.	.	.
CV (%)			13.39	11.9	10.5	13.1	12	10.4
$LSD_{(0.05)}$			0.622	1.19	1.13	0.178	0.848	0.834
SWH			0.0714	0.2018	0.4902	0.166	0.875	0.785
Cropping patterns			0.0024	0.0589	0.0048	.	.	.

Fertility management	0.0001	0.0001	0.0001	0.043	0.013	0.003
SWH*Cropping patterns	0.1575	0.1575	0.2236	.	.	.
SWH*Fertility management	0.0875	0.0875	0.2315	0.022	0.109	0.929
Cropping system*Fertility management	0.2065	0.2065	0.6049	.	.	.
SWH*Cropping patterns*Fertility management	0.4298	0.7318	0.4298	.	.	.

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

The treatment under Tied ridging plus soil fertility amendment of 20N+40P+M2.5 under mono-cropping system was the highest producer (5.6 t ha^{-1}) of sorghum grain yields in LR 2012 compared to LR 2011 and SR 2011. Cowpea grain yields remained statistically at par in most treatments except in Farmers Practice-Intercropping-20N+40P+M2.5, Tied ridging-Intercropping-40N+40P and Farmer Practice-Intercop-M5 at 0.33 t ha^{-1}, 1.57 and 1.91 t ha^{-1} relative to the control group at 0.14 t ha^{-1}, 0.54 and 0.78 t ha^{-1} in LR 2011, SR 2011 and LR2012, respectively. The Contour Furrow and Farmers Practice Intercropping under soil fertility management options of 40N+40P+M5 and M5 respectively, recorded the highest cowpea yields of 1.9 t ha^{-}1 in LR 2012. Generally, the results also indicated that sorghum and cowpea grain yields production was lowest in experiment treatments regarded as “Controls”.

4.1.5 Treatment Effects of Sorghum and Cowpea Biomass Yields in Mbeere South Sub-County

The sorghum biomass yield during the experimental period ranged from 0.14–4.4 t ha^{-1}. Seasonal performance was SR 2011>LR 2012>LR 2011 (Table 4.5). Generally, sorghum biomass yields did not differ from each other (p>0.05) except the highest producers under (Tied ridging- Monocropping-40N+40P+M5 and Farmer Practice-Intercop-M5) yielding 0.24 t ha^{-1} in LR 2011. No either two or three-way significant interaction effects (p>0.05) between SWH*Cropping patterns*soil fertility managements on sorghum biomass and total dry matter yields in all the three seasons, except LR 2011 where significantly different (p=0.0036) on total dry matter yields were observed.

Biomass and total dry matter yields were significantly influenced by SWH methods (p=0.0027) and cropping patterns (p=<0.0001) in LR 2012 season. Unlike sorghum grain yields results, the Cropping patterns had a significant effect (p=0.0005, p=0.0193 and p=<0.0001, p=0.0008) on biomass and total dry matter yields in SR 2011 and the LR 2012, respectively. Further, the soil fertility management options affected sorghum biomass and total dry matter yields significantly ($p<0.0001$) in LR 2011, SR 2011 and LR 2012 (Table 4.5).

Table 4.5: Sorghum Stovers and Total Dry Matter Yields in Various Treatments at Mariari Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

Soil Water Harvesting	**Cropping system**	**Soil fertility amendment practices**	**Biomass + Husks (t/ha)**			**Total Dry Matter (t/ha)**		
			LR 2011	**SR 2011**	**LR 2012**	**LR 2011**	**SR 2011**	**LR 2012**
Tied- ridging	Monocropping	40N+40P	0.19ab	3.8ab	3.1b	0.34bc	6.6ab	5.1bc
Tied- ridging	Monocropping	20N+40P	0.20ab	3.5ab	2.5bc	0.39bc	5.5b	4.6c
Tied- ridging	Monocropping	40N+40P+M5	0.24a	4.1ab	3.2ab	0.47bc	7.3a	5.2bc
Tied- ridging	Monocropping	M5	0.21ab	4.1ab	3.7ab	0.40bc	6.5ab	5.6bc
Tied- ridging	Monocropping	20N+40P+M2.5	0.20ab	4.7a	4.1a	0.78a	7.1ab	7.8a
Tied- ridging	Monocropping	Control	0.07b	1.9c	0.5d	0.14c	2.9d	1.4d
Tied- ridging	Intercropping	40N+40P+M5	0.14ab	3.0bc	3.0b	0.23c	5.6b	5.9bc
Tied- ridging	Intercropping	M5	0.20ab	2.7bc	3.0b	0.29bc	4.8bc	4.6c
Tied- ridging	Intercropping	40N+40P	0.18ab	2.9bc	2.9bc	0.35bc	5.1bc	5.1bc
Tied- ridging	Intercropping	20N+40P+M2.5	0.22ab	3.1bc	3.0b	0.42bc	5.7ab	5.9bc
Tied- ridging	Intercropping	20N+40P	0.23ab	3.0bc	3.0b	0.77a	6.0ab	5.6bc
Tied- ridging	Intercropping	Control	0.07b	1.3c	0.4d	0.13c	2.2d	1.2d
Farmers Practice	Monocropping	40N+40P+M5	0.11b	2.8bc	3.3ab	0.23c	5.3b	4.5c
Farmers Practice	Monocropping	M5	0.16ab	3.7ab	2.5bc	0.36bc	6.4ab	4.2c
Farmers Practice	Monocropping	40N+40P	0.18ab	4.0ab	2.8bc	0.24c	5.9ab	4.6c
Farmers Practice	Monocropping	20N+40P+M2.5	0.17ab	4.0ab	3.2ab	0.34bc	6.2ab	5.1bc
Farmers Practice	Monocropping	20N+40P	0.16ab	3.5ab	3.5ab	0.63ab	6.0ab	5.7bc
Farmers Practice	Monocropping	Control	0.04b	1.9c	0.2d	0.07c	2.5d	0.8d
Farmers Practice	Intercropping	20N+40P	0.12b	4.0ab	2.7bc	0.28bc	6.5ab	4.0c
Farmers Practice	Intercropping	40N+40P	0.17ab	2.5bc	2.3bc	0.33bc	5.1b	3.6c
Farmers Practice	Intercropping	20N+40P+M2.5	0.18ab	3.5ab	2.1bc	0.26bc	5.7ab	3.7c
Farmers Practice	Intercropping	40N+40P+M5	0.17ab	4.0ab	2.2bc	0.49bc	7.2a	3.8c
Farmers Practice	Intercropping	M5	0.24a	3.4b	2.1bc	0.58ab	6.1ab	3.8c
Farmers Practice	Intercropping	Control	0.04b	1.8c	0.2d	0.08c	2.4d	0.7d
Contour furrow	Monocropping	40N+40P+M5	0.15ab	3.5ab	3.1b	0.28bc	6.1ab	4.5c
Contour furrow	Monocropping	40N+40P	0.22ab	3.3b	3.4ab	0.35bc	6.1ab	5.2bc
Contour furrow	Monocropping	20N+40P+M2.5	0.17ab	3.7ab	3.1b	0.28bc	6.1ab	5.5bc
Contour furrow	Monocropping	20N+40P	0.23ab	4.1ab	3.6ab	0.50b	6.0ab	6.2b
Contour furrow	Monocropping	M5	0.18ab	2.6bc	3.3ab	0.26bc	4.8bc	5.3bc
Contour furrow	Monocropping	Control	0.06b	1.7c	0.3d	0.13c	3.1d	1.0d
Contour furrow	Intercropping	40N+40P+M5	0.19ab	3.3b	2.1bc	0.31bc	5.6b	3.8c
Contour furrow	Intercropping	40P20 N	0.12b	3.0bc	2.2bc	0.20c	5.4b	4.0c
Contour furrow	Intercropping	M5	0.11b	3.4b	2.1bc	0.15c	5.4b	3.9c
Contour furrow	Intercropping	40N+40P	0.20ab	3.2b	3.0b	0.37bc	6.0ab	5.0bc
Contour furrow	Intercropping	40N+40P+M2.5	0.19ab	3.2b	2.2bc	0.41bc	5.6b	4.1c
Contour furrow	Intercropping	Control	0.06b	1.4c	0.3d	0.17c	3.3c	1.1d

CV (%)	11.8	23	24.3	44.8	18.9	32.6
$LSD_{(0.05)}$	0.11	1.21	0.97	0.25	1.66	1.56
SWH	0.7558	0.4114	0.0027	0.1864	0.6355	<0.0001
Cropping patterns	0.4904	0.0005	<0.0001	0.6373	0.0193	0.0008
Fertility management	<0.0001	0.0001	<0.0001	0.0001	0.0001	<0.0001
SWH*Cropping patterns	0.2443	0.5267	0.1028	0.299	0.629	0.3035
SWH*Fertility management	0.8991	0.6936	0.1278	0.2985	0.6451	0.1763
Cropping system*Fertility management	0.8758	0.5294	0.1583	0.9359	0.2118	0.1932
Water*Cropping patterns*Fertility management	0.7839	0.0542	0.6136	0.0036	0.3607	0.4054

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

The highest sorghum biomass and total dry matter yields were recorded under the same SWH method (Tied ridging) and cropping system (monocropping) but in various soil fertility management options (i.e., 40N+40P+M5 and 20N+40P+M2.5) at 0.24 t ha^{-1}, 4.7 t ha^{-1} and 4.1 t ha^{-1} and 0.78 t ha^{-1}, 7.1 t ha^{-1} and 7 t ha^{-1} in LR 2011, SR 2011 and LR 2012, respectively (Table 4.5). Similarly, the lowest biomass and total dry matter yields i.e., 0.07 t ha^{-1}, 1.9 and 0.5 t ha^{-1} and 0.15 t ha^{-1}, 3.3 t ha^{-1} and 1.4 t ha^{-1} were recorded in treatments regarded as experiment “controls” during the LR 2011, SR 2011 and LR 2012 seasons, respectively. And were significant lower ($p<0.05$) than the rest of treatments in their respective seasons.

The results (Table 4.6) indicated that cowpea biomass and total dry matter yields differed significantly (p=0.0039, p=0.0497) and (p=0.0023, p=0.0514) during SR 2011 and LR 2012 seasons, respectively. The results further indicated that there were no cowpea biomass yields recorded during the LR 2011 season (Figure 3.2). Similar to the observations on cowpea grain yields, the biomass and total dry matter yields were significantly influenced by soil fertility management options (p=0.0001, p=0.0307) and (p=0.0005, p=0.0069) in SR 2011 and LR 2012 seasons, respectively. There was, however, no effect or even 2-way interactions (p>0.05) of SWH methods and SWH*fertility management on cowpea biomass and total dry matter yield during the 2 seasons.

Table 4.6: Cowpea Stovers and Total Dry Matter Yields in Various Treatments at Mariari Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

Soil Water Harvesting	**Cropping system**	**Soil fertility amendment practices**	**Biomass + husks (t/ha)**		**Total Dry Matter (t/ha)**	
			Short rains 2011	**Long rains 2012**	**Short rain 2011**	**Long rain 2012**
Tied ridging	Intercropping	40N+40P+M5	3.08ab	3.1a	4.08a	3.9a
Tied ridging	Intercropping	M5	2.75ab	2.2ab	3.60ab	2.8ab
Tied ridging	Intercropping	40N+40P	2.82ab	1.7bc	3.70ab	3.0ab
Tied ridging	Intercropping	20N+40P+M2.5	3.48a	2.2ab	4.14a	2.2bc
Tied ridging	Intercropping	20N+40P	2.61ab	2.2ab	3.47ab	3.0ab
Tied ridging	Intercropping	Control	0.61c	0.7c	0.76c	0.9c
Contour furrow	Intercropping	40N+40P+M2.5	2.56a	2.2ab	3.48ab	2.9ab
Contour furrow	Intercropping	40N+40P+M5	2.13b	2.4ab	2.64ab	3.2ab
Contour furrow	Intercropping	20N+40P	1.76bc	1.9b	2.35b	2.9ab
Contour furrow	Intercropping	M5	2.45ab	1.7bc	3.16ab	2.4bc
Contour furrow	Intercropping	40N+40P	1.97bc	1.6bc	2.59ab	2.2bc
Contour furrow	Intercropping	Control	0.39c	0.6c	0.54c	0.8c
Farmers Practice	Intercropping	20N+40P	2.21ab	1.7bc	3.08ab	2.1bc
Farmers Practice	Intercropping	40N+40P	2.19ab	1.4bc	2.93ab	1.9bc
Farmers Practice	Intercropping	20N+40P+M2.5	1.91bc	2.1ab	2.67ab	2.8ab
Farmers Practice	Intercropping	40N+40P+M5	2.79ab	2.1ab	3.45ab	3.0ab
Farmers Practice	Intercropping	M5	2.66ab	1.9b	3.96a	2.5b
Farmers Practice	Intercropping	Control	0.30c	0.5c	0.41c	0.6c
CV (%)			36.1	36.9	32.6	33.9
$LSD_{(0.05)}$			1.33	1.13	1.58	1.38
p value			0.0039	0.0497	0.0023	0.0514
SWH			0.2892	0.6223	0.2447	0.5912
Fertility management			0.0001	0.0307	0.0005	0.0069
SWH* Fertility management			0.2683	0.8436	0.2045	0.8938

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

Similar to sorghum biomass and total dry matter yields, the highest cowpea biomass and total dry matter yields were recorded under the same SWH method (Tied ridging) but in a different soil fertility management practices (that is, 40N+40P+M5 and 20N+40P+M2.5) yielding (3.48 t ha^{-1} and 3.1 t ha^{-1}) and (4.14 t ha^{-1} and 3.9 t ha^{-1}) were recorded during the SR 2011 and LR 2012 seasons, respectively (Table 4.6). The least yields (0.61 t ha^{-1}) and (0.7 t ha^{-1}) and (0.76 t ha^{-1} and 0.9 t ha^{-1}) were recorded in treatments regarded as "control" respectively.

4.1.6 Treatments Effect of Sorghum and Cowpea Biomass Yields (T/Ha) in Kirinyaga West Sub-County

In Kirinyaga West, sorghum biomass performance was higher during SR 2011 and LR 2012 while LR 2011 had very low yields (Table 4.7). The results from the current study did not show any significant interaction effects among the study factors over the entire research period. Sorghum biomass and total dry matter yields differed significantly ($p<0.0006$, $p=0.0003$, $p=0.049$) and ($p<0.0002$, $p<0.0001$, $p=0.0514$) in LR 2011, SR 2011 and LR 2012, respectively.

Soil fertility management options effects on sorghum biomass and total dry matter yields were significant ($p<0.0001$) over the studied seasons. Similar observations were noted on SWH methods on sorghum biomass and total dry matter yields during LR 2011 and LR 2012 (Table 4.7). But during SR 2011 biomass and total dry matter yields were insignificant. Cropping system had significant effect ($p=0.0242$, $p=0.0082$, $p<0.0001$) and ($p=0.0057$, $p=0.0049$, $p=0.0429$) on sorghum biomass and total dry matter yield in LR 2011, SR 2011 and LR 2012, respectively (Table 4.7).

Table 4.7: Sorghum Stovers and Total Dry Matter Yields in Various Treatments in at Karima Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

			Biomass + Husks (t/ha)			**Total Dry Matter (t/ha)**		
Soil Water Harvesting	**Cropping system**	**Soil fertility amendment practices**	**Long rain 2011**	**Short rain 2011**	**Long rain 2012**	**Long rain 2011**	**Short rain 2011**	**Long rain 2012**
Tied ridging	Monocropping	20N+40P	1.07^{ab}	4.0^{ab}	3.1^{bc}	1.8^{ab}	6.6^{ab}	6.0^{cd}
Tied ridging	Monocropping	20N+40P+M2.5	1.05^{ab}	4.9^{a}	7.1^{a}	2.6^{a}	8.4^{a}	12.0^{a}
Tied ridging	Monocropping	40N+40P	0.90^{ab}	3.0^{bc}	3.4^{bc}	1.3^{bc}	5.8^{bc}	6.7^{bc}
Tied ridging	Monocropping	40N+40P+M5	1.47^{a}	2.8^{bc}	2.2^{bc}	1.2^{bc}	4.4^{bc}	4.6^{cd}
Tied ridging	Monocropping	M5	0.56^{bc}	1.9^{c}	2.0^{bc}	1.0^{bc}	3.5^{cd}	4.0^{cd}
Tied ridging	Monocropping	Control	0.11^{bc}	1.1^{c}	0.3^{c}	0.2^{c}	1.7^{d}	1.2^{de}
Tied ridging	Intercropping	20N+40P	0.52^{bc}	2.7^{bc}	2.8^{bc}	0.7^{bc}	3.9^{c}	5.5^{cd}
Tied ridging	Intercropping	20N+40P+M2.5	0.68^{b}	2.1^{bc}	3.1^{bc}	1.0^{bc}	3.9^{c}	5.6^{cd}
Tied ridging	Intercropping	40N+40P	0.51^{bc}	1.5^{c}	3.5^{bc}	0.8^{bc}	3.4^{cd}	6.2^{c}
Tied ridging	Intercropping	40N+40P+M5	0.95^{ab}	2.8^{bc}	1.6^{c}	1.6^{ab}	4.8^{bc}	4.2^{cd}
Tied ridging	Intercropping	M5	0.57^{bc}	3.8^{ab}	3.8^{b}	0.8^{bc}	7.2^{ab}	6.8^{bc}
Tied ridging	Intercropping	Control	0.10^{c}	0.9^{c}	0.3^{c}	0.2^{c}	1.5^{d}	1.1^{de}
Contour furrow	Monocropping	20N+40P	1.37^{ab}	4.8^{ab}	2.9^{bc}	2.0^{ab}	8.1^{ab}	6.2^{c}
Contour furrow	Monocropping	20N+40P+M2.5	1.12^{ab}	2.4^{bc}	2.3^{bc}	1.9^{ab}	4.6^{bc}	4.7^{cd}
Contour furrow	Monocropping	40N+40P	0.37^{bc}	3.4^{b}	3.3^{bc}	0.7^{bc}	6.2^{b}	5.9^{cd}
Contour furrow	Monocropping	40N+40P+M5	0.87^{ab}	1.3^{c}	2.1^{bc}	1.2^{b}	2.3^{cd}	4.0^{cd}
Contour furrow	Monocropping	M5	0.52^{b}	2.8^{bc}	3.3^{bc}	0.7^{bc}	4.8^{bc}	5.3^{cd}
Contour furrow	Intercropping	Control	0.11^{bc}	1.9^{c}	0.2^{c}	0.2^{c}	2.4^{cd}	0.9^{e}
Contour furrow	Intercropping	40P20 N	0.49^{bc}	1.8^{c}	1.6^{c}	0.7^{bc}	3.7^{cd}	3.5^{d}
Contour furrow	Intercropping	20N+40P+M2.5	1.16^{ab}	2.9^{bc}	3.3^{bc}	1.8^{ab}	5.8^{bc}	5.7^{cd}
Contour furrow	Intercropping	40N+40P	0.72^{bc}	3.0^{bc}	3.8^{b}	1.1^{bc}	5.3^{bc}	7.0^{bc}
Contour furrow	Intercropping	40N+40P+M5	1.06^{ab}	3.1^{bc}	3.3^{bc}	2.0^{ab}	5.1^{bc}	6.6^{bc}
Contour furrow	Intercropping	M5	0.21^{bc}	1.6^{c}	1.6^{c}	0.3^{bc}	3.0^{cd}	3.5^{d}
Contour furrow	Intercropping	Control	0.11^{bc}	1.4^{c}	0.2^{c}	0.2^{c}	1.9^{cd}	1.0^{de}
Farmers Practice	Monocropping	20N+40P	0.77^{b}	1.8^{c}	2.1^{bc}	1.0^{bc}	3.2^{cd}	4.2^{cd}
Farmers Practice	Monocropping	20N+40P+M2.5	1.16^{ab}	3.0^{bc}	2.1^{bc}	2.1^{ab}	5.3^{bc}	5.3^{cd}
Farmers Practice	Monocropping	40N+40P	1.02^{ab}	2.5^{bc}	1.4^{c}	1.9^{ab}	4.4^{bc}	2.8^{de}
Farmers Practice	Monocropping	40N+40P+M5	0.73^{bc}	2.8^{bc}	2.5^{bc}	2.6^{a}	5.2^{bc}	6.1^{c}
Farmers Practice	Monocropping	M5	0.67^{bc}	3.0^{bc}	2.4^{bc}	1.0^{bc}	5.6^{bc}	5.1^{cd}
Farmers Practice	Monocropping	Control	0.08^{c}	1.0^{c}	0.2^{c}	0.1^{c}	1.4^{d}	0.7^{e}
Farmers Practice	Intercropping	20N+40P	0.76^{bc}	2.6^{bc}	1.5^{c}	0.9^{bc}	4.5^{bc}	3.8^{cd}
Farmers Practice	Intercropping	20N+40P+M2.5	0.84^{ab}	2.1^{bc}	1.6^{c}	1.4^{b}	3.8^{c}	3.7^{cd}
Farmers Practice	Intercropping	40N+40P	0.87^{ab}	2.0^{bc}	3.2^{bc}	1.6^{ab}	3.6^{cd}	5.5^{cd}
Farmers Practice	Intercropping	40N+40P+M5	0.93^{ab}	3.1^{bc}	5.2^{ab}	1.5^{ab}	5.6^{bc}	9.1^{b}
Farmers Practice	Intercropping	M5	0.47^{bc}	1.8^{c}	1.5^{c}	0.8^{bc}	3.2^{cd}	2.9^{de}
Farmers Practice	Intercropping	Control	0.05^{c}	0.7^{c}	0.2^{c}	0.1^{c}	1.0^{d}	0.6^{e}
CV (%)			58.8	35.7	52.0	61.6	28.1	36.2
$LSD_{(0.05)}$			0.663	1.43	2.01	1.15	2.01	2.54
p value			0.0006	0.0003	0.049	0.0002	<0.0001	<0.0001
SWH			0.0538	0.1209	0.0027	0.0502	0.0691	0.0228
Cropping patterns			0.0242	0.0082	<0.0001	0.0057	0.0049	0.0429
Fertility management			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0389

SWH*Cropping patterns	0.5101	0.1278	0.1028	0.2937	0.1426	0.6005
SWH*Fertility management	0.3957	0.0839	0.1278	0.1912	0.0594	0.3530
Cropping system*Fertility management	0.8980	0.1666	0.1583	0.6226	0.1396	0.4734
Water*Cropping patterns*fertility management	0.6950	0.2833	0.6136	0.6145	0.2446	0.7863

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

The highest sorghum biomass and total dry matter yields were recorded under the same SWH method (Tied ridging) and cropping system (monocropping) but in a different soil fertility management options (i.e., 40N+40P+M5 and 20N+40P+M2.5) reporting (1.47 t ha^{-1}, 4.9 t ha^{-1} and 7.1 t ha^{-1}) and (2.6 t ha^{-1}, 8.4 t ha^{-1} and 12.0 t ha^{-1}) in LR 2011, SR 2011 and LR 2012, respectively (Table 4.7). While the lowest yields below (0.11 t ha^{-1}, 1.4 and 0.3 ha^{-1}) and (0.2 ha^{-1} , 2.3 ha^{-1} and 1.2 ha^{-1}) were recorded in treatments regarded as experimental "controls" and they were significant lower ($p<0.05$) from the top producers in their respective seasons.

Cowpea biomass performance was higher during the SR 2011 and LR 2012 seasons while LR 2011 had very low yields (Table 4.8). These results were significantly different (p=0.0006, p=0.0003, p=0.049) and (p=0.0002, p=0.0001, p=0.0514) in LR 2011, SR 2011 and LR 2012, respectively. Soil fertility management options had significant effect (p=0.008 and p=0.0027) and (p=0.0005 and p>0.0001) on cowpea biomass and total dry matter yields in SR 2011 and LR 2012 seasons, respectively, but not in LR 2011 (Table 4.8).

Table 4.8: Cowpea Stovers and Total Dry Matter Yields in Various Treatments at Karima Site During the LR 2011, SR 2011 and LR 2012 Cropping Seasons

Soil water harvesting	Cropping system	Soil fertility amendment practices	Long rain 2011	Short rain 2011	Long rain 2012	Long rain 2011	Short rain 2011	Long rain 2012
Tied ridging	Intercropping	20N+40P	0.5c	3.1b	2.4bc	0.7bc	3.7b	3.8b
Tied ridging	Intercropping	20N+40P+M2.5	0.6c	3.5ab	2.2bc	0.7bc	4.4ab	3.6bc
Tied ridging	Intercropping	40N+40P	0.5c	3.5ab	2.0bc	0.6c	4.4ab	3.5bc
Tied ridging	Intercropping	40N+40P+M5	1.1bc	3.7ab	2.8b	1.4b	4.5ab	4.3bc
Tied ridging	Intercropping	M5	2.2a	4.7a	3.0ab	2.3a	5.9a	4.8ab
Tied ridging	Intercropping	Control	0.4c	1.4c	0.9c	0.5c	1.6c	1.7d
Contour furrow	Intercropping	20N+40P	0.8c	2.6bc	1.7c	1.0bc	2.9bc	3.1c
Contour furrow	Intercropping	20N+40P+M2.5	1.5b	2.6bc	2.8b	1.7ab	3.7b	4.7ab
Contour furrow	Intercropping	40N+40P	1.1bc	4.3ab	3.9a	1.3bc	5.3ab	5.8a
Contour furrow	Intercropping	40N+40P+M5	1.2bc	3.4ab	2.6bc	1.4b	4.3ab	4.1bc
Contour furrow	Intercropping	M5	0.8c	2.7bc	1.4c	0.9bc	3.2bc	2.6c
Contour furrow	Intercropping	Control	0.8c	1.1c	1.0c	0.9bc	1.4c	1.7d
Farmers Practice	Intercropping	20N+40P	0.9bc	3.1b	1.7c	1.1bc	4.0b	3.1c
Farmers Practice	Intercropping	20N+40P+M2.5	1.1bc	3.6ab	2.4bc	1.3bc	4.4ab	3.8bc
Farmers Practice	Intercropping	40N+40P	0.7c	3.4ab	1.7c	0.9bc	4.1b	3.1c
Farmers Practice	Intercropping	40N+40P+M5	0.7c	2.9b	2.5bc	1.0bc	3.8b	4.6b
Farmers Practice	Intercropping	M5	0.3c	2.5bc	1.9bc	0.4c	3.6b	3.4c
Farmers Practice	Intercropping	Control	0.8c	0.77c	0.9c	1.0bc	0.98c	1.3d
CV (%)			24.6	29.5	29.3	22.1	26.8	18.6
$LSD_{(0.05)}$			0.67	1.49	1.04	0.76	1.69	1.11
p value			0.0962	0.0121	0.0055	0.0137	0.0121	<0.0001
SWH			0.6669	0.9107	0.5570	0.6271	0.6712	0.3842
Fertility management			0.1717	0.0008	0.0027	0.2534	0.0005	<0.0001
SWH* Fertility management			0.2269	0.1875	0.0797	0.2552	0.1709	0.0179

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

The highest cowpea biomass and dry matter yields were recorded under different SWH method (Tied ridging and Contour furrows) and different soil fertility management options (40N+40P and M5) at 2.2 t ha^{-1}, 4.7 t ha^{-1} and 2.4 t ha^{-1} and 2.3 t ha^{-1}, 5.9 and 5.8 t ha^{-1}) in LR 2011, SR 2011 and LR 2012, respectively (Table 4.8). However, the lowest biomass and total dry matter yields of 0.8 t ha^{-1}, 1.4 t ha^{-1} and 0.9 t ha^{-1} and 0.6 t ha^{-1}, 1.6 and 1.7 t ha^{-1} in the control in LR 2011, SR 2011 and LR 2012, respectively, and were significant different ($p<0.05$) from the rest of the treatments, respectively.

4.2 Soil Water Harvesting Technologies, Integrated Soil Fertility Management and Cropping Patterns Effect on Soil Properties

4.2.1 Treatment effects of soil chemical properties in Mbeere South Sub-County

Soil pH at the beginning of the study ranged from 4.1–5.9 (Table 4.9). The results of soil pH values were recorded varied significantly (p<0.0001) at the beginning and end of the experiment period. By end of the study period, the soil pH had significant increased (t-test, p<0.05) in all the treatments, except in the Control group which did not record a significant increase at the end of experiment (t-test, p>0.05). The highest increase in soil pH levels were recorded in manure added treatments, these plots showed pH ranging from 5.8–6.3 during the end of the last cropping season.

Total N was differed significantly (p<0.0006) at the beginning but not at end of the study (p=0.4851). Total soil N in all the treatments increased significantly at the end of the study (t-test, p<0.05), except in the control group (t-test, p>0.05). Soil organic carbon and available P values were varied significantly (p<0.0001) if compared at the beginning and end of the study period (Table 4.10). The soil organic carbon and P increased significantly in all the treatments except experiment "controls" where a significant decrease (t-test, p<0.05) were observed. Exchangeable K, Mg and Ca showed similar trends to those of soil pH, N, C and P that there was a significant increase (t-test, p<0.05) in all the treatments except in the control group which had a significant decrease (t-test, p>0.05).

Table 4.9: Treatment Effect on Soil pH, N and Total C at the Beginning and End of Experiment at Mariari Study Site

SWH	Cropping pattern	Soil fertility amendment practices	pH				N				% C			
			Beginning	**End**	**Change**	***t*-test, *p***	**Beginning**	**End**	**Change**	***t*-test, *p***	**Beginning**	**End**	**Change**	***t*-test, *p***
TR	Intercropping	20N+40P	5.5b	5.7cd	+0.267	0.054	0.15a	0.19b	+0.04	0.006	1.7b	2.1cd	+0.467	0.034
TR	Intercropping	M5	5.3b	5.6cd	+0.33	0.025	0.14ab	0.19b	+0.047	0.005	1.5b	2.0cd	+0.567	0.003
TR	Intercropping	40N+40P	5.5b	5.7cd	+0.267	0.054	0.14ab	0.17b	+0.03	0.095	1.9b	2.1cd	+0.267	0.015
TR	Intercropping	40N+40P+M2.5	5.5b	5.7cd	+0.190	0.017	0.13ab	0.19b	+0.057	0.003	1.6b	2.5b	+0.9	0.004
TR	Intercropping	40N+40P+M5	5.4b	5.7cd	+0.243	0.054	0.13ab	0.19b	+0.053	0.004	1.5b	2.8a	+1.3	0.001
TR	Intercropping	Control	5.4b	5.7cd	+0.253	0.155	0.15a	0.17b	+0.023	0.118	1.6b	1.3f	-1.3	0.001
TR	Monocropping	40N+40P+M5	5.5b	5.8bc	+0.267	0.008	0.15a	0.19b	+0.047	0.034	1.2b	2.2c	+1.0	0.003
TR	Monocropping	M5	5.9a	6.0b	+0.933	0.030	0.15a	0.17b	+0.023	0.020	1.7b	2.1cd	+0.467	0.034
TR	Monocropping	20N+40P	5.4b	5.6cd	+0.253	0.003	0.14ab	0.19b	+0.050	0.13	1.4b	2.5b	+1.1	0.003
TR	Monocropping	40N+40P+ M5	5.5b	5.7cd	+0.18	0.019	0.14ab	0.18b	+0.047	0.034	1.9b	2.1cd	+0.267	0.015
TR	Monocropping	20N+40P+M2.5	5.7ab	6.0b	+0..3	0.035	0.14ab	0.19b	+0.05	0.013	1.8b	2.3bc	+0.533	0.026
TR	Monocropping	Control	5.5b	5.7cd	+0.18	0.176	0.15a	0.19b	+0.033	0.199	2.5b	1.4ef	-1.033	0.007
CF	Intercropping	20N+40P+M2.5	5.5b	5.8bc	+0.3	0.035	0.14ab	0.19b	+0.043	0.006	1.4b	1.6e	+0.233	0.020
CF	Intercropping	20N+40P	5.5b	5.7cd	+0.233	0.020	0.15a	0.17b	+0.027	0.015	1.9b	2.1cd	+0.267	0.015
CF	Intercropping	40N+40P	5.5b	5.7cd	+0.2	0.012	0.12b	0.19b	+0.07	0.003	1.6b	2.5b	+0.90	0.028
CF	Intercropping	40N+40P+M5	5.5b	5.8bc	+0.3	0.035	0.15a	0.19b	+0.037	0.008	1.4b	2.5b	+1.1	0.003
CF	Intercropping	M5	5.5b	5.8bc	+0.243	0.013	0.13ab	0.19b	+0.053	0.004	1.5b	2.7ab	+1.193	0.043
CF	Intercropping	Control	5.4b	5.6cd	+0.213	0.214	0.15a	0.19b	+0.04	0.147	2.3b	1.7de	-0.667	0.031
CF	Monocropping	40N+40P	5.5b	5.7cd	+0.233	0.020	0.15a	0.18b	+0.030	0.035	1.7b	2.1cd	+0.467	0.034
CF	Monocropping	20N+40P+M2.5	5.9a	6.0b	+0.107	0.047	0.14ab	0.19b	+0.043	0.023	1.7b	2.3bc	+0.633	0.003
CF	Monocropping	20N+40P	5.5b	5.7cd	+0.227	0.003	0.14ab	0.17b	+0.027	0.015	1.8b	2.0cd	+0.20	0.054
CF	Monocropping	40N+40P+M5	5.5b	5.8bc	+0.267	0.054	0.12b	0.19b	+0.067	0.002	1.5b	2.5b	+1	0.003
CF	Monocropping	M5	5.9a	6.0b	+0.107	0.047	0.15a	0.19b	+0.040	0.020	1.5b	2.4bc	+0.933	0.034
CF	Monocropping	Control	5.5b	5.6cd	+0.133	0.383	0.11bc	0.12b	+0.003	0.423	2.1b	1.8e	-0.23	0.020
FP	Intercropping	20N+40P	5.5b	5.7cd	+0.233	0.001	0.14ab	0.18b	+0.04	0.037	1.4b	2.0cd	+0.6	0.004
FP	Intercropping	40N+40P	5.4b	5.6cd	+0.253	0.003	0.14ab	0.19b	+0.047	0.005	1.9b	2.1cd	+0.267	0.015
FP	Intercropping	20N+40P+M2.5	4.2c	6.3a	+2.143	0.001	0.15a	0.19b	+0.040	0.020	1.6b	2.5b	+0.90	0.028

FP	Intercropping	M5	5.5b	5.8bc	+0.267	0.008	0.15a	0.17b	+0.023	0.020	1.4b	2.5b	+1.1	0.003
FP	Intercropping	40N+40P+M5	5.5b	5.8bc	+0.3	0.035	0.15a	0.17b	+0.017	0.038	1.5b	2.1c	+0.6	0.032
FP	Intercropping	Control	5.4b	5.7cd	+0.253	0.155	0.09c	0.17b	+0.073	0.269	1.7b	2.2 c	-0.533	0.004
FP	Monocropping	20N+40P	5.5b	5.7cd	+2.333	0.020	0.15a	0.20b	+0.05	0.013	1.7b	2.1cd	+0.467	0.034
FP	Monocropping	20N+40P+M2.5	5.5b	5.8bc	+0.267	0.008	0.13ab	0.19b	+0.060	0.009	1.6b	2.5b	+0.867	0.010
FP	Monocropping	40N+40P+M5	5.5b	5.8bc	+0.30	0.035	0.15a	0.18b	+0.037	0.008	2.6a	2.8a	+0.2	0.054
FP	Monocropping	40N+40P	5.5b	5.7cd	+0.233	0.001	0.13ab	0.18b	+0.057	0.003	1.4b	2.5b	+1.1	0.003
FP	Monocropping	M5	5.9a	6.0b	+0.107	0.047	0.15a	0.17b	+0.023	0.020	1.9b	2.1cd	+0.267	0.015
FP	Monocropping	Control	5.4b	5.6cd	+0.213	0.214	0.14ab	7.12a	+6.98	0.420	2.1b	1.8de	-0.3	0.035
CV			2.04	2.36			7.51	534.78			76.24	6.65		
LSD			0.18	0.22			0.02	3.26			2.53	0.22		
p-value$_{(0.05)}$			<0.0001	<0.0001			0.0006	0.4851			<0.0001	<0.0001		

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. SWH=Soil water harvesting, TR=tied ridges, CF=contour furrows, FP=farmers practice, Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

Table 4.10: Treatment Effect on Available Soil P, Exchangeable K, Ca and Mg at the Beginning and End of Experiment at Mariari Study Site

SW H	Cropping ıtterns	Soil fertility amendment practice	(ppm) P				(ppm) K				(ppm) Ca				(ppm) Mg			
			Beginnin g	End	Change	*t*-test, *p*	Beginning	End	Change	*t*-test, *p*	Beginning	End	Change	*t*-test, *p*	Beginnin g	End	Change	*t*-test, *p*
TR	Intercropping	20N+40P	69.3bc	82b	+12.73	0.002	765.9a	825.9a	+60.0	0.001	1254.4a	1408.9a	+154.5	0.12	312.6g	377.2c	+64.7	0.002
TR	Intercropping	M5	79a	89.8a	+10.43	0.010	560.2ab	756.7ab	+196.5	0.001	833c	1217.3bc	+384.3	0.0001	420ef	504b	+83.93	0.0001
TR	Intercropping	40N+40P	71.8ab	86.5a	+14.67	0.004	627.3ab	1313.6a	+686.3	0.001	1532.8a	1889.2a	+356.37	0.002	418ef	502.8b	+184.9	0.002
TR	Intercropping	20N+40P+M2.5	57.6c	75.7ab	+18.03	0.0001	337.9c	729.2b	+391.2	0.005	940.4bc	1215.5bc	+275.03	0.009	312.6g	377.2c	+64.7	0.002
TR	Intercropping	40N+40P+M5	79.8a	92.9a	+13.17	0.002	557.6ab	757.1ab	+199.5	0.002	1109.1ab	1331.2abc	+222.0	0.038	519.9d	603.7a	+83.73	0.006
TR	Intercropping	Control	62.07c	43.3d	-18.73	0.0001	929.8a	969.7a	+39.8	0.0001	1313.6a	1274.5ab	-39.1	0.009	541.3d	483.8b	-57.5	0.0001
TR	Monocropping	40N+40P+M5	79.4a	82.4b	+3.0	0.057	550bc	756.3ab	+205.8	0.001	1251.3a	1710.7a	+459.4	0.0001	309.7g	479.7b	+170	0.004
TR	Monocropping	M5	78.1a	106.3a	+28.2	0.002	1303.6a	1852.8a	+652.8	0.003	419.3d	1514.9abc	+337.9	0.010	419.3ef	505.3b	+86	0.001
TR	Monocropping	20N+40P	82.60a	83.7ab	+1.067	0.18	729.6a	868.8a	+139.7	0.000	1154.4ab	1602.9abc	+448.5	0.002	442.6e	485.9b	+43.33	0.01
TR	Monocropping	40N+40P	69.6bc	92.5a	+22.83	0.002	550.13bc	855.4a	+305.2	0.000	1427.2a	1884.8a	+457.6	0.001	442.6e	485.9b	+43.33	0.01
TR	Monocropping	20N+40P+M2.5	68.bc	86.7a	+18.67	0.001	746.9a	867.6a	+120.6	0.040	1155.4ab	1601.1abc	+445.8	0.001	439.7e	388.6c	-51.17	0.066
TR	Monocropping	Control	52.4c	41.3d	-11.10	0.0001	729.8a	769.6ab	+39.83	0.001	1306.6a	1275.6ab	-30.93	0.002	722.9c	376.1c	-347.77	0.001
CF	Intercropping	20N+40P+M2.5	72.9ab	84.b	+11.03	00.007	555.9bc	757.5ab	+201.5	0.000	1249.8a	1500.8abc	+250.93	0.001	440.9e	552.2a	+111.37	0.551
CF	Intercropping	20N+40P	67.5bc	97.7a	+30.13	0.001	664.7ab	1319.5a	+654.8	0.004	1528.7a	1886.9a	+358.3	0.000	420ef	504b	+83.93	0.0001
CF	Intercropping	40N+40P	57.4c	75.8ab	+18.4	0.003	336.6c	711.1b	+374.5	0.000	932.0bc	1211.5bc	+279.5	0.003	276.6h	378.4c	+101.8	0.084
CF	Intercropping	40N+40P+M5	82.8a	83.5ab	+0.7	0.206	729.3a	868.97a	+139.7	0.0001	1157.7ab	1587.4abc	+429.73	0.005	420.9ef	602.3a	+181.43	0.001
CF	Intercropping	M5	54.9c	75.7ab	+20.83	0.0001	335.2c	706.97b	+371.8	0.0001	925.4bc	1219.5bc	+294.03	0.0001	310.1g	374.3c	+64.2	0.007
CF	Intercropping	Control	96.3a	72.4b	-23.93	0.001	335.7c	536.0c	+200.3	0.540	1326.7a	1275.4ab	-51.23	0.156	440.8e	384.1c	-56.63	0.002
CF	Monocropping	40N+40P	78.2a	96.8a	+18.67	0.001	730.2a	867.33a	+137.2	0.0001	1152.2ab	1610.1abc	+457.9	0.0001	309.7g	479.7b	+170	0.004
CF	Monocropping	20N+40P+M2.5	72.9ab	96a	+130	0.095	1592.4a	1051.8a	-540.6	0.0001	485.9d	442.6d	+540.53	0.013	442.6e	485.9b	+43.33	0.01
CF	Monocropping	20N+40P	68.bc	86.7a	+18.67	0.001	741.5a	1410.6a	+669.1	0.002	1627.9a	1869.2a	+241.3	0.007	519.9d	603.7a	+83.73	0.006
CF	Monocropping	40N+40P+M5	57.3c	76c	+18.70	0.001	335.8c	709.33b	+373.5	0.0001	913.9bc	1217.8bc	+303.83	0.002	308.6g	377.1c	+68.5	0.008
CF	Monocropping	M5	80.8a	83.8ab	+3.033	0.021	730.2a	868.3a	+138.1	0.0001	1154.9ab	1605.4abc	+450.5	0.0001	419.3ef	505.3b	+86	0.001
CF	Monocropping	Control	85.9b	83.6a	-2.4	0.005	729.3a	770.8ab	+41.45	0.005	1155.3ab	442.6d	-713.7	0.0001	435.6e	383.8c	-51.77	0.008
FP	Intercropping	20N+40P	57.6c	75.7ab	+18.03	0.0001	555bc	443.87c	-111.13	0.001	15.2d	997.6d	+982.4	0.0001	409.6f	479.1b	+69.57	0.001

FP	Intercropping	40N+40P	70.1cbc	92.2a	+22.07	0.002	547.9c	656.37bc	+108.5	0.001	1307.2a	1271ab	+36.13	0.065	420ef	504b	+83.93	0,0001
FP	Intercropping	20N+40P+M2.5	42.8d	82.7ab	+39.9	0.0001	729.5a	868.7a	+139.2	0.001	1055.5ab	1409.8a	+354.30	0.003	409.6f	479.1b	+69.57	0.001
FP	Intercropping	M5	78.2a	96.8a	+18.67	0.001	515.9c	1412.5a	+896.6	0.0001	1631.4a	1697.4a	+65.93	0.006	523.3d	603.1a	+79.83	0.001
FP	Intercropping	40N+40P+M5	73.8ab	76.9bc	+3.1	0.007	630.1ab	1300.9a	+670.9	0.001	1547.9a	1868.6a	+320.63	0.017	418ef	501.7b	+83.7	0.004
FP	Intercropping	Control	78a	76bc	-1.967	0.035	620.1ab	1119.6a	+499.5	0.000	1215.4ab	1174.3c	-41.1	0.055	439.4e	384c	-55.4	0.013
FP	Monocropping	20N+40P	52.3c	81ab	+28.73	0.0001	730.2a	966.0a	+235.8	0.000	1156.4ab	1608.7abc	+452.3	0.001	519.9d	603.7a	+83.73	0.006
FP	Monocropping	20N+40P+M2.5	58.6c	75.6ab	+17.0	0.008	334.8c	705.87b	+371.0	0.000	928bc	1210bc	+282.2	0.001	311.7g	378.5c	+66.8	0.001
FP	Monocropping	40N+40P+M5	63.4c	73.8b	+10.40	0.0001	739a	860.03a	+121.0	0.000	1054bc	1594.8abc	+540.47	0.001	420.9ef	602.3a	+181.4	0.001
FP	Monocropping	40N+40P	57.9c	75.5ab	+17.67	0.001	437.9c	605.47c	+167.5	0.001	829.2c	1117.0c	+287.77	0.0001	409.6f	479.1b	+69.57	0.001
FP	Monocropping	M	58.1c	86.4a	+28.27	0.001	615.2ab	1314.8a	+699.6	0.000	1531a	1889.8a	+358.8	0.0001	417.2ef	501.8b	+84.6	0.003
FP	Monocropping	Control	96.3a	72.4b	-23.93	0.001	560.8ab	754.57ab	+193.8	0.003	1404.2a	1375abc	-29.17	0.013	738.6bc	380.7c	-357.97	0.001
CV			2.06	1.8			4.17	8.78			2.34	1.53			3.21	11.08		
LSD			2.36	2.38			41.04	127.52			56.66	29.45			25.67	78.88		
p-value$_{(0.05)}$			<0.0001	<0.0001			<0.0001	<0.0001			<0.0001	<0.0001			<0.0001	<0.0001		

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. SWH=Soil water harvesting, TR=tied ridges, CF=contour furrows, FP=farmers practice, Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

4.2.2 Treatment Effects of Soil Chemical Properties in Kirinyaga West Sub-County

Soil pH levels measurements at the beginning of the experiment ranged from 4.6 to 5.5 (Table 4.11). The soil pH values varied significantly ($p<0.0001$) at the onset and end of the last cropping season. The highest increase in soil pH levels ranging from 5.7 to 6 were recorded in some selected manure added treatments of 40N+40P+M5 and 40N+40P+M2.5 during the last cropping season. Similarly, total N and SOC values were significantly different ($p<0.0001$) before and after the experimentation.

Available P differed significantly ($p<0.0001$) at the beginning and end of the current research. Soil P increased significantly in all the treatments except in experiment “controls” where soil P decreased significantly (t-test, $p<0.05$) (Table 4.15). Exchangeable K, Mg and Ca values followed similar trends at the beginning and to the last cropping season. But experiment “controls” recorded a minimal increase although they remained significantly lower ($p<0.05$) than the rest of the treatments.

Table 4.11: Treatment Effect on Soil pH, N and Total C at the Beginning and End of Experiment at Karima Study Site

			(ppm) pH				(ppm) N				(%) C			
SWH	**Cropping patterns**	**Soil fertility amendment practices**	**Beginning**	**End**	**Change**	***t*-test, *p***	**Beginning**	**End**	**Change**	***t*-test, *p***	**Beginning**	**End**	**Change**	***t*-test, *p***
TR	Intercropping	20N+40P	5.2^{b}	5.7bc	+0.5	0.003	0.18ab	0.28ab	+0.1	0.029	1.9d	2.2d	+0.13	0.054
TR	Intercropping	M5	5.4^{ab}	5.6c	+0.25	0.019	0.19a	0.23bc	+0.04	0.008	2.5a	2.9a	+0.35	0.012
TR	Intercropping	40N+40P	5.2^{bc}	5.6c	+0.46	0.001	0.18ab	0.22d	+0.043	0.006	1.5f	1.7fg	+0.2	0.074
TR	Intercropping	20N+40P+M2.5	4.8^{de}	5.7bc	+0.94	0.002	0.16b	0.19e	+0.03	0.038	2.0cd	2.6b	+0.61	0.003
TR	Intercropping	40N+40P+M5	5.4^{ab}	5.6b	+0.4	0.027	0.19a	0.24bc	+0.05	0.006	1.4f	1.8f	+0.4	0.007
TR	Intercropping	Control	5.2^{bc}	5.7bc	+0.45	0.008	0.18ab	0.23bc	+0.05	0.005	1.9d	2.5b	+0.53	0.004
TR	Monocropping	40N+40P+M5	5.3^{b}	5.9ab	+0.43	0.000	0.19a	0.23bc	+0.04	0.006	1.9d	2.1de	+0.27	0.015
TR	Monocropping	M5	4.7^{e}	5.3de	+0.67	0.017	0.16b	0.19e	+0.03	0.038	1.6ef	2.1de	+0.47	0.005
TR	Monocropping	20N+40P	5.4^{ab}	5.7bc	+0.3	0.035	0.18ab	0.25b	+0.05	0,020	2.5a	3.0a	+0.46	0.054
TR	Monocropping	40N+40P	4.8^{de}	5.7bc	+0.89	0.004	0.18ab	0.22d	+0.043	0.006	2.1c	2.3cd	+0.23	0.020
TR	Monocropping	20N+40P+M2.5	5.2^{bc}	5.7bc	+0.47	0.20	0.18ab	0.23bc	+0.053	0.004	2.0cd	2.6b	+0.61	0.003
TR	Monocropping	Control	5.2^{bc}	5.6c	+0.41	0.001	0.18ab	0.19e	+0.01	0.038	1.8de	2.3cd	+0.49	0.014
CF	Intercropping	20N+40P+M2.5	5.5^{a}	5.9c	+0.41	0.001	0.18ab	0.28ab	+0.1	0.029	2.5a	3.0a	+0.46	0.054
CF	Intercropping	20N+40P	5.3^{b}	5.7bc	+0.46	0.004	0.17ab	0.30a	+0.13	0.054	1.9d	2.2d	+0.3	0.035
CF	Intercropping	40N+40P	5.4^{ab}	5.7bc	+0.26	0.012	0.18ab	0.22d	+0.043	0.006	1.4f	2.4c	+1.0	0.003
CF	Intercropping	40N+40P+M5	5.1^{c}	5.8b	+0.7	0.007	0.19a	0.23bc	+0.04	0.006	2.0cd	2.6b	+0.61	0.003
CF	Intercropping	M5	4.9^{d}	5.2e	+0.27	0.054	0.18ab	0.23bc	+0.047	0.02	1.6ef	1.8f	+0.19	0.009
CF	Intercropping	Control	4.8^{de}	4.9f	+0.17	0.038	0.19a	0.22d	+0.03	0.043	1.8de	2.3cd	+0.49	0.014
CF	Monocropping	40N+40P	5.2^{bc}	5.4d	+0.13	0.014	0.18ab	0.22d	+0.043	0.006	1.9d	2.5bc	+0.95	0.001
CF	Monocropping	20N+40P+M2.5	4.9^{d}	5.8b	+0.87	0.006	0.18ab	0.23bc	+0.047	0.02	2.2bc	2.3cd	+0.13	0.054
CF	Monocropping	20N+40P	4.8^{de}	5.7bc	+0.87	0.006	0.18ab	0.23bc	+0.047	0.02	1.0g	2.3cd	+0.42	0.005
CF	Monocropping	40N+40P+M5	5.1^{c}	5.4d	+0.3	0.035	0.19a	0.25b	+0.06	0.003	1.4f	2.4c	+1.0	0.003
CF	Monocropping	M5	5.1^{c}	5.5cd	+0.4	0.041	0.18ab	0.19e	+0.01	0.038	2.5a	3.0a	+0.46	0.054
CF	Monocropping	Control	4.8^{de}	5.7bc	+0.87	0.006	0.15bc	0.17ef	+0.02	0.074	1.7e	1.8f	+0.17	0.003
FP	Intercropping	20N+40P	5.2^{bc}	5.6c	+0.42	0.047	0.18ab	0.23bc	+0.047	0.02	1.8de	2.0e	+0.21	0.012
FP	Intercropping	40N+40P	4.9^{d}	5.4d	+0.5	0.013	0.18ab	0.21de	+0.03	0.015	2.5a	3.0a	+0.46	0.054

FP	Intercropping	20N+40P+M2.5	5.2^{bc}	6.0a	+0.77	0.002	0.18ab	0.23bc	+0.053	0.004	1.9d	2.2d	+0.33	0.011
FP	Intercropping	M5	4.9^{d}	5.2e	+0.3	0.35	0.18ab	0.23bc	+0.05	0.020	1.8de	2.0e	+2.37	0.024
FP	Intercropping	40N+40P+M5	5.4^{ab}	6.0a	+0.62	0.001	0.17ab	0.19e	+0.02	0.020	1.9d	2.2d	+0.23	0.007
FP	Intercropping	Control	4.6^{e}	5.0f	+0.43	0.006	0.15bc	0.16g	+0.013	0.054	1.8de	2.1d	+0.23	0.054
FP	Monocropping	20N+40P	4.9^{d}	5.6c	+0.7	0.007	0.18ab	0.23bc	+0.047	0.02	2.1c	2.3cd	+0.23	0.020
FP	Monocropping	20N+40P+M2.5	5.3^{b}	5.6c	+0.37	0.008	0.17ab	0.22d	+0.05	0.013	1.8de	2.0e	+2.37	0.024
FP	Monocropping	40N+40P+M5	5.1^{c}	5.7bc	+0.6	0.009	0.18ab	0.22d	+0.04	0.020	2.5a	3.0a	+0.46	0.054
FP	Monocropping	40N+40P	5.1^{c}	5.6c	+0.43	0.006	0.18ab	0.23bc	+0.053	0.004	1.7e	1.8f	+0.17	0.003
FP	Monocropping	M5	5.3^{b}	5.6c	+0.37	0.032	0.18ab	0.21de	+0.03	0.015	1.9d	2.3cd	+0.41	0.005
FP	Monocropping	Control	5.1^{c}	5.7bc	+0.63	0.019	0.15bc	0.19e	+0.04	0.020	1.7e	1.8f	+0.17	0.003
CV			1.7	1.1			6.0	5.8			4.5	4.1		
LSD			0.14	0.10			0.02	0.14			0.15	0.14		
p-value$_{(0.05)}$			<0.0001	<0.0001			0.0001	0.0001			<0.0001	<0.0001		

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. SWH=Soil water harvesting, TR=tied ridges, CF=contour furrows, FP=farmers practice, Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

Table 4.12: Treatment Effect on Available P, Exchangeable K, Ca and Mg at the Beginning and End of Experiment at Karima Study Site

			(ppm) P				(ppm) K				(ppm) Ca				(ppm) Mg			
SWH	**Cropping patterns**	**Soil fertility amendment practices**	**Beginning**	**End**	**Change**	***t*-test, *p***	**Beginning**	**End**	**Change**	***t*-test, *p***	**Beginning**	**End**	**Change**	***t*-test, *p***	**Beginning**	**End**	**Change**	***t*-test, *p***
TR	Intercropping	20N+40P	66.9cd	96.6bc	+29.66	0.001	728.1e	868.8g	+140.7	0.0001	1152.7de	1610.8g	+458.1	0.0001	441.1e	505i	+63.9	0.001
TR	Intercropping	OM5	57.7d	74.3d	+16.53	0.001	334.3j	855.1g	+520.76	0.0001	1055.2e	1221.3o	+166.1	0.0001	310.1i	393.9n	+83.77	0.001
TR	Intercropping	40N+40P	75.0bc	92.6c	+17.53	0.001	712.4f	854.5g	+142.07	0.0001	1270.6cd	1729.2e	+458.6	0.0001	380.4h	521.4h	+141	0.001
TR	Intercropping	20N+40P+M2.5	75.7bc	82.4d	+6.7	0.001	729.1e	869.6g	+140.51	0.0001	928.9e	1894.1d	+965.2	0.0001	419.6f	740.4c	+320.8	0.001
TR	Intercropping	40N+40P+M5	79.1bc	91.7cd	+12.57	0.004	555.8i	754.8h	+199.0	0.0001	931.1e	1896.4cd	+965.3	0.0001	840.5a	1520.0a	+679.5	0.001
TR	Intercropping	Control	77.6bc	75.8d	-1.86	0.004	617.3h	705.8i	+88.5	0.0001	1304.3cd	1370.8k	+66.47	0.002	378.4h	385.6o	+7.17	0.015
TR	Monocropping	40N+40P+M5	69.4cd	77.0d	+7.52	0.001	869.0d	970.2e	+101.2	0.0001	1304cd	1627.4f	+323.4	0.0001	419.2f	682.9d	+263.7	0.00
TR	Monocropping	OM5	78.1bc	105.4b	+27.27	0.002	618.2h	1310.5b	+692.3	0.0001	1531.3b	1901.9c	+370.5	0.0001	419.7f	505i	+85.27	0.001
TR	Monocropping	20N+40P	56.9d	76.2d	+19.27	0.001	335.4j	708.23j	+372.87	0.0001	929.1e	1219.9o	+290.7	0.0001	309.2n	1486.0a	+1176.0	0.403
TR	Monocropping	40N+40P	75.2bc	92.3c	+17.03	0.002	701.6f	856.5g	+154.93	0.0001	1531.3b	1901.9c	+370.5	0.0001	376.7i	521.4h	+144.7	0.001
TR	Monocropping	40N+40P+M2.5	55.5d	62.4e	+6.92	0.001	729.2e	869.7g	+140.48	0.0001	1153.7de	1609.6g	+455.9	0.0001	442.0e	501.4i	+59.4	0.001
TR	Monocropping	Control	83.6b	82.1cd	-1.47	0.016	705.5f	756.7h	+51.13	0.0001	1304.3cd	1370.8k	+66.47	0.002	384.2h	385.9o	+1.7	0.003
CF	Intercropping	20N+40P+M2.5	69.3cd	72.9de	+3.54	0.003	735.0e	869.7g	+134.7	0.001	1280.0cd	1730.1e	+450.1	0.0001	442.3e	682.9d	+240.6	0.00
CF	Intercropping	20N+40P	66.9cd	96.6bc	+29.66	0.001	617.4h	1321.2b	+703.77	0.0001	1535.8b	1897.5cd	+361.6	0.0001	420.1f	505.3i	+85.27	0.00
CF	Intercropping	40N+40P	58.3d	75.9d	+17.53	0.001	324.8j	705.0i	+380.27	0.0001	932.9j	1317.4m	+384.5	0.0001	311.6i	375.6p	+63.97	0.009
CF	Intercropping	40N+40P+M5	79.1bc	91.7cd	+12.57	0.004	918.4c	1276.1c	+357.7	0.0001	2052.7a	2254.9a	+202.2	0.0001	412.6f	482.7j	+70.1	0.00
CF	Intercropping	OM5	39.0e	40.6fg	+1.56	0.02	645.7g	865.7g	+220.07	0.0001	1304cd	1627.4f	+323.4	0.0001	596.1c	798.4b	+202.3	0.00
CF	Intercropping	Control	77.3bc	75.5d	-1.77	0.005	555.8i	704.7i	+86.6	0.0001	1305cd	1629.0f	+323.9	0.0001	421.8f	436.1l	+14.23	0.003
CF	Monocropping	40N+40P	79.1bc	91.7cd	+12.57	0.004	555.8i	1420.9a	+865.08	0.0001	930.1e	1896.3cd	+966.2	0.0001	419.4f	682.9d	+263.5	0.001
CF	Monocropping	20N+40P+M2.5	11.6f	83.9cd	+72.33	0.001	1306.9a	1420.9a	+114.0	0.001	1048.6e	1507.7i	+459.1	0.0001	404.1g	486.3j	+82.13	0.00
CF	Monocropping	20N+40P	49.4de	60.2e	+10.87	0.001	933.7b	1072.4d	+138.7	0.0001	1531.3b	1901.9c	+370.4	0.0001	402.9g	477.5k	+74.57	0.00
CF	Monocropping	40N+40P+M5	57.8d	75.5d	+17.7	0.004	334.8j	703.9i	+369.1	0.0001	929.7e	1220.3o	+290.6	0.0001	305.8i	378.6p	+72.73	0.00
CF	Monocropping	OM5	56.2d	69.4de	+13.21	0.001	735.8e	854.9g	+119.1	0.0001	1270.6cd	1729.2e	+458.6	0.0001	443.3e	740.4c	+297.07	0.00

CF	Monocropping	Control	75.9bc	74.4d	-1.54	0.017	868.8d	958.1e	+89.3	0.0001	1381.3c	1454.2j	+72.9	0.001	393.8gh	433.7l	+39.87	0.00
FP	Intercropping	20N+40P	32.1e	55.2ef	+23.14	0.001	558.5i	970.2e	+411.70	0.0001	928.9e	1894.1d	+965.2	0.0001	398.3g	530.7g	+132.4	0.000
FP	Intercropping	40N+40P	56.3d	200.1a	+143.8	0.422	736.2e	1286.4bc	+550.18	0.0001	1504bc	1729.8e	+225.8	0.0001	442.4e	555.9e	+113.5	0.00
FP	Intercropping	20N+40P+M2.5	55.5d	62.4e	+6.92	0.001	922.0bc	1071.4d	+149.4	0.0001	1631b	2222.9b	+591.9	0.0001	741.8b	800.3b	+58.5	0.00
FP	Intercropping	OM5	31.5e	54.5ef	+23.04	0.001	555.4i	975.2e	+419.79	0.0001	1053.7e	1153.7p	+100.0	0.001	396.2g	543.7f	+137.53	0.00
FP	Intercropping	40N+40P+M5	71.0c	76.5d	+5.53	0.13	555.1i	1313.2b	+758.1	0.0001	1531.3b	1901.9c	+370.5	0.0001	752.3b	800.3b	+.87.0	0.002
FP	Intercropping	Control	83.4b	82.3cd	-1.08	0.002	884.0d	972.5e	+88.59	0.0001	1378c	1458.5j	+80.5	0.0001	383.4h	385.7o	+2.25	0.00
FP	Monocropping	20N+40P	49.4de	60.2e	+10.87	0.001	1311.3a	1420.9a	+109.9	0.0001	1054.9e	1529.7h	+474.8	0.0001	502.4d	740.4c	238.0	0.00
FP	Monocropping	20N+40P+M2.5	42.3e	46.3f	+3.96	0.004	1311.3a	1420.9a	+109.6	0.0001	1053.7e	1340.0l	+286.3	0.0001	503.0d	682.9d	+179.9	0.001
FP	Monocropping	40N+40P+M5	57.3d	74.0d	+16.73	0.002	334.2j	861.1g	+527.01	0.0001	1053.3e	1220.3o	+167	0.0001	309.7i	395.3n	+85.57	0.00
FP	Monocropping	40N+40P	39.1e	40.7fg	+1.54	0.013	646.7g	932.5f	+285.77	0.0001	1305cd	1629.0f	+323.9	0.0001	597.7c	800.3b	+202.6	0.00
FP	Monocropping	M5	49.6de	59.9e	+10.26	0.001	934.2b	1071.4d	+137.29	0.0001	1154.6de	1609.1g	+454.5	0.0001	402.8g	475.3k	+72.5	0.00
FP	Monocropping	Control	82.2bc	80.7d	-1.48	0.098	616.6h	705.4i	+88.83	0.0001	1381.3c	1454.2j	+72.9	0.001	442.1e	482.7j	+40.6	0.00
CV			11.7	9.9			1.2	2.1			7.1	0.28			1.4	0.55		
LSD			11.81	11.49			14.23	31.49			145.84	6.98			10.46	4.19		
p-value(0.05)			<0.0001	<0.0001			<0.0001	<0.0001			0.0001	<0.0001			0.0001	<0.0001		

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. SWH=Soil water harvesting, TR=tied ridges, CF=contour furrows, FP=farmers practice, Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

4.2.3 Treatment effects of soil moisture content in Mbeere South Sub-County

Soil water content measurement levels- were higher during the initial stages of measurements at two-WAP, four-WAP and six-WAP relative to other intervals (Table 4.13). The results showed a general trend that farmers practice SWH method recorded the lowest soil water content measurements at all the intervals of two-WAP as compared to Tied ridging and contour furrows throughout the season. However, monocropping patterns significantly held more soil water content than intercropping systems. A decrease and the lowest soil moisture content were in the "controls" in all the SWH methods but under different Cropping patterns categories at all the two-WAP sampling periods.

However, it was only at two-WAP that there was a significant interaction of the factors in this study. All the other sampling periods did not show any significant interaction. SWH methods and Cropping patterns significantly affected soil water content during all the sampling periods i.e. at two-WAP, four-WAP, six-WAP, eight-WAP and ten-WAP. But there were unnoticeable effects (p=0.0823) of SWH methods on soil water content measurement interval at eight-WAP. However, soil fertility management options significantly affected (p=0.0018 and p=0.0476) soil water content measurement at 2WAP and 10 WAP, respectively.

Table 4.13: Soil Water Content Measurement across Various Weeks after Planting at Mariari Site during the SR 2011 Cropping Season

			Soil Water Content measurement (%) 2 Weeks After Planting (2 WAP)				
Soil water harvesting	**Cropping Patterns**	**Soil fertility amendment practices**	**2WAP**	**4WAP**	**6WAP**	**8WAP**	**10WAP**
Tied ridging	Intercropping	20N+40P	32.0bc	30.7b	18.4b	18.0b	15.4b
Tied ridging	Intercropping	20N+40P+M2.5	37.5ab	36.3ab	27.2ab	23.8ab	15.6b
Tied ridging	Intercropping	40N+40P	29.2bc	30.7b	20.3b	18.9b	15.7b
Tied ridging	Intercropping	40N+40P+M5	39.5ab	35.5ab	21.4b	18.9b	16.2b
Tied ridging	Intercropping	Control	25.0c	30.4b	21.1b	16.1b	14.4b
Tied ridging	Intercropping	M5	33.4bc	30.9b	28.3ab	19.1b	16.7ab
Tied ridging	Monocropping	20N+40P	36.9ab	31.1b	29.9ab	18.9b	21.6ab
Tied ridging	Monocropping	20N+40P+M2.5	45.8a	40.4a	31.6a	28.1a	23.2a
Tied ridging	Monocropping	40N+40P	36.8ab	32.7ab	26.5ab	21.3ab	14.2b
Tied ridging	Monocropping	40N+40P+M5	43.9ab	37.3ab	30.0ab	25.8ab	21.2ab
Tied ridging	Monocropping	Control	28.0bc	25.6b	21.5b	17.7b	13.3b
Tied ridging	Monocropping	M5	36.7ab	38.4ab	27.1ab	27.3ab	15.6b
Contour furrow	Intercropping	20N+40P	32.5bc	33.5ab	21.8b	23.8ab	16.0b
Contour furrow	Intercropping	20N+40P+M2.5	31.0bc	34.8ab	25.2ab	22.8ab	20.6ab
Contour furrow	Intercropping	40N+40P	32.5bc	31.8ab	21.7b	19.3b	15.2b
Contour furrow	Intercropping	40N+40P+M5	35.4b	34.5ab	23.4b	18.4b	20.3ab
Contour furrow	Intercropping	Control	27.6bc	30b	22.9b	15.7b	14.7b
Contour furrow	Intercropping	M5	34.1bc	31.9ab	22.1b	24.3ab	16.0b
Contour furrow	Monocropping	20N+40P	30.4bc	32.4ab	24.7ab	22.0ab	16.4ab
Contour furrow	Monocropping	20N+40P+M2.5	36.1ab	32.8ab	26.1ab	22.1ab	18.0ab
Contour furrow	Monocropping	40N+40P	30.8bc	32.9ab	25.0ab	19.0b	17.1ab
Contour furrow	Monocropping	40N+40P+M5	34.5bc	36.6ab	26.0ab	22.1ab	16.1b
Contour furrow	Monocropping	Control	22.4c	24.8b	17.4b	14.4b	10.4b
Contour furrow	Monocropping	M5	37.2ab	35.5ab	25.5ab	20.1b	16.7ab
Farmers Practice	Intercropping	20N+40P	37ab	30.9b	22.6b	18.0b	20.6ab
Farmers Practice	Intercropping	20N+40P+M2.5	39.1ab	32.2ab	29.7ab	20.0b	19.8ab
Farmers Practice	Intercropping	40N+40P	29.1bc	29b	21.2b	18.9b	15.8b
Farmers Practice	Intercropping	40N+40P+M5	41ab	35.2ab	26.3ab	20.7ab	17.3ab
Farmers Practice	Intercropping	Control	27.9bc	28.7b	20.0b	16.8b	12.0b
Farmers Practice	Intercropping	M5	29.6bc	29.2b	23.5b	19.4b	16.7ab
Farmers Practice	Monocropping	20N+40P	31.1bc	29.1b	23.5b	19.2b	15.3b
Farmers Practice	Monocropping	20N+40P+M2.5	32.6bc	31.8ab	23.2b	20.2ab	15.6b
Farmers Practice	Monocropping	40N+40P	29.1bc	29.6b	21.8b	19.7b	19ab
Farmers Practice	Monocropping	40N+40P+M5	36.4ab	31.4ab	25.5ab	22.4ab	15.3b
Farmers Practice	Monocropping	Control	24.0c	27.0b	21.1b	17.7b	12.9b
Farmers Practice	Monocropping	M5	33.3bc	34.3ab	26.1ab	21.8ab	16.5ab
CV (%)			15.9	15.3	16.7	21.5	22.5
$LSD_{(0.05)}$			9.78	9.08	7.43	8.08	6.9
SWH			0.0028	0.0432	0.0427	0.0823	0.0234
Cropping patterns			0.0331	0.0097	0.0001	0.005	0.0272
Fertility management			0.0018	0.2525	0.29	0.1416	0.0476
SWH*Cropping patterns			0.0243	0.3649	0.1336	0.5226	0.7512
SWH*Fertility management			0.0391	0.574	0.5196	0.6636	0.44
Cropping system*Fertility management			0.0345	0.8326	0.6517	0.499	0.3699
SWH*Cropping patterns*Fertility management			0.5396	0.8432	0.9801	0.9966	0.9123

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea

The treatments under (TR-Monocropping and 20N+40P+M2.5) recorded the highest soil water content measurements of (45.8%, 40.4%, 31.6%, 28.1% and 23.2%) at all the intervals of two-WAP during the whole sampling period of SR 2011 (Table 4.13). This was followed by soil fertility amendment of (40N+40P+M5) and (M5) at all stage intervals of for the whole season. These treatments were significantly superior in terms of soil water content conservation as relative to the rest of the treatments. Manure treatments were among the soil fertility management options that retained higher soil water content measurement as compared to other inorganic fertilizers combinations of (20N+40P and 40N+40P) in their respective Cropping patterns.

Soil water content measurement levels- were higher during the initial stages of measurements at two-WAP, four-WAP and six-WAP relative to other intervals during the LR 2012 season (Table 4.14). Similar results also indicated that monocropping had significantly higher soil water content than those in Intercropping system as observed in the two WAP, four-WAP, six-WAP and eight-WAP measurement sampling intervals. There was a significant effect (p=0.0009, p=0.0029 and p=0.0010) and (p=0.0188, p=0.0669 and p=0.0053) of SWH methods and Cropping patterns on soil water content at two-WAP, four-WAP and six-WAP during the LR 2012 season, respectively. However, there was no evidence of any significant effects (p>0.05) of soil fertility management options on soil water content measurement at all the sampling intervals of two-WAP during the LR 2012 season.

Table 4.14: Soil Water Content Measurement across Various Weeks after Planting at Mariari Site during the LR 2012 Cropping Season

SWH	Cropping patterns	Soil fertility amendment practices	Soil Water Content measurement (%) 2 Weeks After Planting (2 WAP)					
			2WAP	4WAP	6WAP	8WAP	10WAP	12WAP
Tied ridging	Intercropping	20N+40P	24.7b	27.9ab	29.5b	19.8bc	18.1ab	15.9ab
Tied ridging	Intercropping	20N+40P+M2.5	32.7ab	35.8ab	38.2ab	23.1bc	23.3ab	18.0ab
Tied ridging	Intercropping	40N+40P	25.5b	29.6ab	29.9b	20.0bc	16.8ab	15.9ab
Tied ridging	Intercropping	40N+40P+M5	26.2ab	32.1ab	31.7b	21.7bc	20.6ab	16.1ab
Tied ridging	Intercropping	Control	23.7b	26.3b	27.6b	17.9bc	14.6b	13.0b
Tied ridging	Intercropping	M5	26.3ab	30.7ab	41.3ab	20.9b	23.2ab	15.7ab
Tied ridging	Monocropping	20N+40P	27.1ab	37.1a	37.0ab	21.0bc	20.6ab	21.4ab
Tied ridging	Monocropping	20N+40P+M2.5	34.0ab	39.0a	42.9ab	26.6ab	25.0a	22.7a
Tied ridging	Monocropping	40N+40P	29.3ab	35.1ab	38.6ab	26.5ab	17.4ab	18.6ab
Tied ridging	Monocropping	40N+40P+M5	35.2a	33.7ab	32.7b	32.2a	19.4ab	22.0ab
Tied ridging	Monocropping	Control	21.3b	25.3b	28.8b	19.6bc	12.9b	13.6ab
Tied ridging	Monocropping	M5	33.9ab	37.2a	43.3a	27.4ab	20.1ab	15.8ab
Contour Furrow	Intercropping	20N+40P	27.3ab	29.5ab	33.8ab	22.6bc	18.9ab	15.4ab
Contour Furrow	Intercropping	20N+40P+M2.5	35.0ab	31.5ab	35.1ab	22.8bc	18.6ab	17.7ab
Contour Furrow	Intercropping	40N+40P	24.7b	29.1ab	31.1b	21.4bc	16.3ab	14.7ab
Contour Furrow	Intercropping	40N+40P+M5	29.7ab	34.5ab	36.5ab	28.6ab	22.1ab	15.0ab
Contour Furrow	Intercropping	Control	22.0b	24.5b	29.1b	19.0bc	13.3b	13.3b
Contour Furrow	Intercropping	M5	28.1ab	32.8ab	35.5ab	24.1ab	21.9ab	17.4ab
Contour Furrow	Monocropping	20N+40P	32.6ab	34.2ab	35.3ab	22.2bc	17.0ab	16.0ab
Contour Furrow	Monocropping	20N+40P+M2.5	30.6ab	36.1ab	35.0ab	29.2ab	19.8ab	18.4ab
Contour Furrow	Monocropping	40N+40P	30.9ab	34.1ab	32.6b	21.8bc	16.6ab	15.9ab
Contour Furrow	Monocropping	40N+40P+M5	31.4ab	37.1a	43.1ab	22.8bc	20.9ab	18.6ab
Contour Furrow	Monocropping	Control	22.6b	25.2b	26.3b	19.5bc	13.7b	12.2b
Contour Furrow	Monocropping	M5	30.3ab	37.9a	39.8ab	23.3bc	19.9ab	17.0ab
Farmers Practice	Intercropping	20N+40P	26.2ab	29.2ab	32.9b	20.0bc	19.7ab	20.2ab
Farmers Practice	Intercropping	20N+40P+M2.5	26.8ab	30.4ab	39.6ab	20.9bc	19.9ab	18.7ab
Farmers Practice	Intercropping	40N+40P	26.0b	29.7ab	31.1b	20.9bc	19.7ab	16.6ab
Farmers Practice	Intercropping	40N+40P+M5	26.4ab	30.6ab	32.1b	24.0b	20.3ab	18.2ab
Farmers Practice	Intercropping	Control	22.4b	23.6b	28.3b	15.2c	15.6b	12.4b
Farmers Practice	Intercropping	M5	26.2ab	31.2ab	33.8ab	23.3bc	20.8ab	18.6ab
Farmers Practice	Monocropping	20N+40P	23.8b	29.2ab	31.6b	23.3bc	16.7ab	13.7ab
Farmers Practice	Monocropping	20N+40P+M2.5	29.5ab	29.0ab	33.5ab	25.7ab	18.7ab	18.0ab
Farmers Practice	Monocropping	40N+40P	26.1ab	27.6ab	29.4b	20.4bc	18.4ab	15.4ab
Farmers Practice	Monocropping	40N+40P+M5	29.3ab	33.1ab	38.1ab	23.0bc	19.3ab	16.9ab
Farmers Practice	Monocropping	Control	22.8b	24.0b	23.8b	18.0bc	14.1b	12.8b
Farmers Practice	Monocropping	M5	23.9b	32.0ab	33.5ab	27.5ab	19.2ab	18.6ab
CV (%)			17.9	17.9	16.6	17.6	26.7	29.7
$LSD_{(0.05)}$			9.14	10.3	10.38	8.19	9.21	9.14
SWH			0.0009	0.0029	0.001	0.8161	0.497	0.5838
Cropping patterns			0.0188	0.0669	0.0053	0.1437	0.9911	0.7757
Fertility management			0.5062	0.286	0.1627	0.2862	0.207	0.363
SWH*Cropping patterns			0.3928	0.356	0.1517	0.697	0.4733	0.6559
SWH*Fertility management			0.3795	0.6537	0.4996	0.2286	0.612	0.7269
Cropping system*Fertility management			0.8061	0.713	0.8646	0.0043	0.6559	0.9314
SWH*Cropping patterns*Fertility management			0.6135	0.6002	0.2307	0.5349	0.8067	0.6435

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea

The highest soil water content measurements were recorded in TR-monocropping system measuring 35.2%, 39%, 43.3%, 32.2%, 25% and 22.7% in all the sampling intervals of two-WAP during the LR 2012 season (Table 4.14). However, the treatments under TR-monocropping system recorded the highest soil water content measurements relative to Intercropping system at all stage intervals of two-WAP for the whole season. Manure added treatments were among the soil fertility management options that retained higher soil water content at all measurements intervals of 2 WAP in their respective cropping system categories. Also, the treatments with added external soil amendment of 20N+40P and 40N+40P recorded the lowest soil water content measurements in their respective cropping patterns categories except in experiment "Controls" which recorded a decrease in soil water content measurement at all sampling intervals at 2 WAP during the LR 2012 season.

Soil water content >40% were recorded in five treatments TR, Intercropping and M5, TR, monocropping and 20N+40P+M2.5, TR, monocropping and M5, CF, monocropping and 20N+40PM5 and CF, monocropping and M5 observed at 6th sampling interval of two-WAP and they were insignificant. Similar to the SR 2011 season results, the decrease in soil water content was recorded in treatments regarded as experiment "controls" in all the SWH methods but in different cropping patterns categories in all the sampling intervals during the LR 2012 season.

4.2.4 Treatment Effects of Soil Moisture Content in Kirinyaga West Sub-County

Soil water content measurement levels were higher during the initial stages of measurements at two-WAP, four-WAP, six-AP and eight-WAP relative to other intervals towards the end of the season (Table 4.15). In SR 2011, there was no significant two-ways interactions effects ($p>0.05$) of SWH*Cropping patterns* soil fertility management options variables on soil water content measurements at 2WAP two-WAP sampling interval, however, there were significant two-way interaction effect ($p=0.0434$, $p=0.0393$ and $p=0.0469$) between SWH*Cropping patterns on soil water content measurement at four-WAP, six-WAP and eight-WAP sampling intervals, respectively. There were significant effects ($p<0.05$) of SWH methods on soil water content measurements at all sampling intervals of two-WAP. But at four-WAP and six-WAP sampling interval was insignificant. Cropping patterns on did not show clear effects soil water content measurements at two-WAP, four-WAP and six-WAP sampling intervals. However, soil fertility management options showed significant effects (p=0.0538 and p=0.0544) on soil water content at six-WAP and eight-WAP sampling intervals, respectively.

Table 4.15: Soil Water Content Measurement across Various Weeks after Planting at Karima Site during the SR 2011 Cropping Season

			Soil Water Content measurement (%) 2 Weeks After Planting (2 WAP)						
SWH	**Cropping patterns**	**Soil fertility amendment practices**	**2WAP**	**4WAP**	**6WAP**	**8WAP**	**10WAP**	**12WAP**	**14WAP**
Tied ridging	Intercropping	20N+40P	21.2ab	21.3ab	19.0b	15.2ab	13.6ab	11.3ab	12.1ab
Tied ridging	Intercropping	20N+40P+M2.5	27.7a	22.1ab	22.2ab	16.1ab	13.8ab	14.5ab	13.5ab
Tied ridging	Intercropping	40N+40P	18.0ab	20.0ab	21.5ab	15.5ab	13.5ab	12.2ab	11.0ab
Tied ridging	Intercropping	40N+40P+M5	22.5ab	26.3a	27.9ab	21.4ab	18.9ab	13.0ab	15.5ab
Tied ridging	Intercropping	Control	17.0b	17.0ab	17.1b	10.7b	8.4b	6.9b	5.8b
Tied ridging	Intercropping	M5	25.1ab	25.7a	30.0a	22.1a	20.1a	16.7ab	13.2ab
Tied ridging	Monocropping	20N+40P	17.8ab	17.6ab	20.8ab	14.2b	12.9ab	10.5b	10.8ab
Tied ridging	Monocropping	20N+40P+M2.5	25.5ab	24.9a	27.6ab	20.3ab	19.3ab	17.2a	16.9a
Tied ridging	Monocropping	40N+40P	21.4ab	19.8ab	22.6ab	15.7ab	15.1ab	12.8ab	10.4ab
Tied ridging	Monocropping	40N+40P+M5	26.7ab	26.1a	26.7ab	15.9ab	15.6ab	14.4ab	14.6ab
Tied ridging	Monocropping	Control	17.5b	14.6b	13.9b	12.2b	9.5b	8.8b	8.9b
Tied ridging	Monocropping	M5	22.7ab	20.6ab	22.9ab	15.7ab	15.0ab	13.6ab	11.9ab
Contour Furrow	Intercropping	20N+40P	19.3ab	18.1ab	19.3b	15.0ab	12.1b	9.9b	9.1b
Contour Furrow	Intercropping	20N+40P+M2.5	17.6ab	18.2ab	20.5ab	19.4ab	15.3ab	10.7ab	10.7ab
Contour Furrow	Intercropping	40N+40P	18.2ab	18.0ab	18.8b	16.2ab	13.2ab	11.1ab	10.3b
Contour Furrow	Intercropping	40N+40P+M5	23.4ab	22.3ab	22.3ab	16.3ab	17.4ab	14.0ab	11.0b
Contour Furrow	Intercropping	Control	16.3b	16.2ab	16.9b	11.5b	10.2b	9.7b	8.9b
Contour Furrow	Intercropping	M5	22.9ab	22.6ab	23.6ab	18.1ab	16.9ab	15.1ab	11.8ab
Contour Furrow	Monocropping	20N+40P	23.7ab	20.4ab	20.1ab	15.7ab	14.4ab	12.2ab	10.4ab
Contour Furrow	Monocropping	20N+40P+M2.5	21.5ab	22.6ab	23.8ab	17.2ab	16.1ab	14.3ab	13.5ab
Contour Furrow	Monocropping	40N+40P	23.4ab	22.3ab	22.1ab	17.2ab	16.8ab	13.9ab	12.3ab
Contour Furrow	Monocropping	40N+40P+M5	25.6ab	20.0ab	22.6ab	18.0ab	17.7ab	15.8ab	15.2ab
Contour Furrow	Monocropping	Control	15.6b	13.0b	14.9b	9.0b	11.2b	9.0b	8.0b
Contour Furrow	Monocropping	M5	26.6ab	23.9ab	25.7ab	17.5ab	16.5ab	15.5ab	12.6ab
Farmers Practice	Intercropping	20N+40P	18.2ab	19.3ab	18.4b	13.2b	12.4b	12.1ab	9.7b
Farmers Practice	Intercropping	20N+40P+M2.5	18.6ab	23.6ab	24.6ab	17.7ab	12.4b	13.7ab	9.9b
Farmers Practice	Intercropping	40N+40P	17.7ab	19.2ab	19.6ab	12.8b	12.2b	9.9b	9.1b
Farmers Practice	Intercropping	40N+40P+M5	22.6ab	23.6ab	25.3ab	13.7b	15.8ab	12.5ab	11.8ab
Farmers Practice	Intercropping	Control	12.2b	11.0b	12.4b	9.3b	8.4b	7.3b	5.1b
Farmers Practice	Intercropping	M5	21.7ab	21.1ab	24.0ab	16.6ab	15.4ab	13.5ab	12.3ab
Farmers Practice	Monocropping	20N+40P	21.7ab	20.7ab	18.0b	12.6b	11.5b	11.7ab	10.4ab
Farmers Practice	Monocropping	20N+40P+M2.5	21.4ab	21.5ab	26.5ab	16.8ab	15.2ab	14.6ab	13.1ab
Farmers Practice	Monocropping	40N+40P	19.7ab	20.7ab	21.0ab	15.4ab	13.8ab	12.3ab	10.8ab
Farmers Practice	Monocropping	40N+40P+M5	22.1ab	21.0ab	22.7ab	16.3ab	15.5ab	16.6ab	15.4ab
Farmers Practice	Monocropping	Control	12.5b	12.7b	12.8b	8.6b	7.9b	7.6b	5.8b
Farmers Practice	Monocropping	M5	22.4ab	23.1ab	24.6ab	15.5ab	14.5ab	13.0ab	12.6ab
CV (%)			26.5	27.3	26.5	27.5	28.6	28.7	31.2
$LSD_{(0.05)}$			10.18	10.26	10.55	7.85	7.48	6.63	6.50
SWH			0.0264	0.0561	0.1089	0.0106	0.003	0.0362	0.0119
Cropping patterns			0.1835	0.2699	0.2777	0.2148	0.0042	0.0193	0.0395

Fertility management	0.1457	0.1341	0.0538	0.0544	0.0641	0.158	0.1105
SWH*Cropping patterns	0.343	0.0434	0.0393	0.0469	0.228	0.1606	0.3882
SWH*Fertility management	0.5859	0.6825	0.4263	0.6854	0.8137	0.4006	0.4199
Cropping system*Fertility management	0.6853	0.7156	0.3397	0.4862	0.5063	0.4677	0.2135
SWH*Cropping patterns*Fertility management	0.772	0.8934	0.9024	0.9024	0.8925	0.8467	0.9895

Note: Treatments means having a similar letter in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea

The treatments under TR-Intercropping system recorded the highest soil water content measurements as compared to Monocropping system at all sampling intervals of 2 WAP in the whole season (Table 4.15). Similarly, manure added treatments were among the soil fertility management options that retained higher soil water content measurements at all sampling intervals in their respective cropping system categories. At the same time treatments with added external soil amendment of 20N+40P and 40N+40P recorded the lowest soil water content measurements in their respective cropping patterns categories. The experiment “controls” recorded the least amount of soil water content measurement during the whole sampling and it decreased over the entire sampling time.

The soil water content measurement levels were uniform in all the stages of measurements during the LR 2012 season (Table 4.16). The LR 2012 was the longest season with soil water content measurement intervals of 16-WAP relative to the rest of the seasons in 2 study sites. Intercropped treatments retained significantly higher soil water content measurements than those Monocropping. There were significant interaction effects of SWH*Cropping patterns on soil water content measurement at all sampling intervals of two-WAP in the whole season. Contrarily results also indicated that there was a significant interaction effects (p=0.0325, p=0.0509, p=0.0045 and p=0.0104) of SWH*soil fertility amendments on soil water content measurement at four-WAP, six-WAP, ten-WAP and fourteen-WAP sampling intervals, respectively. On the other hand, interactions between the other factors remained insignificant. SWH methods and soil fertility management options significantly affected soil water content measurements at all the sampling intervals of two-WAP in the whole season. Cropping patterns did not show significant effects on soil water content measurement at all sampling intervals.

Table 4.16: Soil Water Content Measurement across Various Weeks after Planting at Karima during the LR 2012 Cropping Season

SWH	Cropping patterns	Soil fertility amendment practices	Soil Water Content measurement (%) 2 Weeks After Planting (2 WAP)							
			2WAP	4WAP	6WAP	8WAP	10WAP	12WAP	14WAP	16WAP
TR	Intercropping	20N+40P	22.5bc	30.5ab	29.2ab	21.7ab	22.4b	19.5ab	21.2ab	16.3ab
TR	Intercropping	20N+40P+M2.5	29.6ab	33.8ab	36.5ab	28.0ab	30.1ab	24.6ab	26.8a	23.6a
TR	Intercropping	40N+40P	20.4bc	22.0bc	25.6b	20.0ab	19.8bc	19.9ab	17.4bc	15.5b
TR	Intercropping	40N+40P+M5	32.0a	35.3a	35.8ab	29.3a	29.0ab	26.7a	24.2ab	22.4ab
TR	Intercropping	Control	11.8c	17.3bc	20.8bc	16.3b	15.2b	15.2b	13.2bc	12.5bc
TR	Intercropping	M5	30.8ab	33.0ab	39.5a	29.1a	30.9a	26.3ab	25.3ab	20.5ab
TR	Monocropping	20N+40P	19.6bc	19.8bc	23.6b	17.6b	17.0bc	15.8b	15.1bc	13.9bc
TR	Monocropping	20N+40P+M2.5	28.4ab	32.1ab	36.4ab	27.6ab	30.0ab	25.2ab	25.1ab	21.7ab
TR	Monocropping	40N+40P	20.4bc	22.4bc	26.5b	19.7ab	20.0bc	17.0ab	16.5bc	15.0b
TR	Monocropping	40N+40P+M5	22.7b	24.6b	27.0ab	21.3ab	21.2bc	20.1ab	16.9bc	15.6b
TR	Monocropping	Control	16.1bc	15.3bc	18.5bc	16.0b	14.0bc	15.5b	11.9bc	11.8bc
TR	Monocropping	M5	20.5bc	23.3bc	27.1ab	21.8ab	20.3bc	22.0ab	17.7bc	16.7ab
CF	Intercropping	20N+40P	18.6bc	20.3bc	22.1bc	19.4ab	23.6ab	18.9ab	18.5bc	15.3bc
CF	Intercropping	20N+40P+M2.5	25.3ab	27.5ab	30.4ab	24.0ab	27.0ab	21.8ab	20.1ab	19.8ab
CF	Intercropping	40N+40P	20.9b	24.1bc	21.5bc	18.2b	16.2bc	21.6ab	14.1bc	18.9ab
CF	Intercropping	40N+40P+M5	21.3bc	25.3ab	30.6ab	24.2ab	25.4ab	22.5ab	19.7ab	20.9ab
CF	Intercropping	Control	13.2c	13.4c	18.0bc	14.1b	13.6c	11.6b	10.9c	10.8bc
CF	Intercropping	M5	27.3ab	31.3ab	34.9ab	26.3ab	25.9ab	22.8ab	22.3ab	21.7ab
CF	Monocropping	20N+40P	15.9bc	17.7bc	25.7b	22.6ab	21.9bc	19.3ab	18.0bc	15.0bc
CF	Monocropping	20N+40P+M2.5	20.5bc	25.4ab	29.7ab	24.1ab	22.6ab	21.5ab	20.4ab	18.3ab
CF	Monocropping	40N+40P	21.5bc	22.7bc	26.3b	21.8ab	22.3b	19.4ab	20.4ab	12.7bc
CF	Monocropping	40N+40P+M5	25.0ab	28.0ab	33.2ab	26.6ab	25.0ab	23.9ab	20.8ab	20.1ab
CF	Monocropping	Control	13.4c	9.5c	17.6bc	10.1b	12.3c	10.5b	6.8c	7.7c
CF	Monocropping	M5	22.6b	22.7bc	26.8b	25.6ab	22.7ab	20.8ab	24.3ab	17.0ab
FP	Intercropping	20N+40P	17.0bc	20.2bc	23.3bc	16.4b	16.1bc	16.1b	14.4bc	12.8bc
FP	Intercropping	20N+40P+M2.5	19.8bc	23.4bc	32.1ab	17.6b	18.8bc	21.6ab	14.5bc	13.3bc
FP	Intercropping	40N+40P	20.7bc	22.7bc	24.0b	17.6b	18.6bc	16.4b	13.8bc	12.5bc
FP	Intercropping	40N+40P+M5	25.2ab	24.8b	33.2ab	20.7ab	25.9ab	16.6ab	20.6ab	17.4ab
FP	Intercropping	Control	8.2c	13.3c	15.0bc	11.6b	13.4c	10.7ab	8.0c	8.3bc
FP	Intercropping	M5	26.5ab	27.6ab	29.4ab	24.2ab	23.5ab	19.1ab	18.6bc	15.5b
FP	Monocropping	20N+40P	18.0bc	21.3bc	25.3b	18.9b	19.4bc	15.7b	15.9bc	14.3bc
FP	Monocropping	20N+40P+M2.5	21.8bc	26.5ab	29.2ab	22.5ab	23.8ab	20.9ab	20.1ab	17.9ab
FP	Monocropping	40N+40P	16.7bc	18.0bc	20.9bc	21.5ab	16.6bc	15.6b	13.9bc	15.1bc
FP	Monocropping	40N+40P+M5	21.8bc	30.4ab	34.7ab	25.4ab	23.2ab	23.0ab	22.8ab	22.1ab
FP	Monocropping	Control	12.5c	13.7c	11.0c	13.1b	9.4c	8.9b	8.3c	6.6c
FP	Monocropping	M5	23.5ab	28.0ab	33.1ab	25.1ab	27.3ab	21.2ab	18.7b	17.6ab
CV (%)			23.4	23.8	24.9	25.3	24.4	28.4	22.3	25.5
$LSD_{(0.05)}$			9.11	10.36	12.51	9.94	8.45	10.16	7.35	7.68
SWH			0.0001	0.0003	0.0014	0.0060	0.0001	0.0024	0.0001	0.0002

Cropping patterns	0.5795	0.8867	0.7609	0.6087	0.6055	0.6282	0.5498	0.8627
Fertility management	0.0023	0.0018	0.0217	0.0368	0.007	0.0571	0.0005	0.0056
SWH*Cropping patterns	0.0131	0.0023	0.0110	0.0091	0.001	0.0455	0.0001	0.0047
SWH*Fertility management	0.2028	0.0325	0.0509	0.1697	0.0045	0.206	0.0104	0.0788
Cropping system*Fertility management	0.4555	0.3461	0.5584	0.7630	0.4521	0.8006	0.4664	0.7347
Water*harvesting*Cropping patterns*Fertility management	0.1608	0.0684	0.2082	0.5459	0.144	0.7469	0.2964	0.2118

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. SWH=Soil water harvesting, TR=tied ridges, CF=contour furrows, FP=farmers practice, Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea

The treatments under TR-Intercropping system recorded the highest soil water content measurements ranging from 23.6% to 39.5% as compared to Monocropping system at all sampling intervals of 2 WAP in the whole season (Table 4.16). Manure added treatments were among the soil fertility management options that retained higher soil water content measurements at all sampling intervals in their respective SWH methods and cropping system categories. These were followed by treatments with added external soil amendment of 20N+40P and 40N+40P in their respective cropping patterns categories. Similarly, a decrease and the lowest moisture levels were recorded in farmers practice SWH methods with the lowest soil water content measurement in all experiment "Controls".

4.3 Farmers Evaluation of Crop Performance on Sorghum Productivity under Selected Soil Water Harvesting Techniques and Soil Fertility Amendments Practices

4.3.1 Farmer's Evaluation on Treatments Performance in Mbeere South Sub-County

The adult females respondents were the majority (34.4%) involved in the treatment evaluation followed by adult males (30%) (Figure 4.1). The youth females were 17.2% with the least representative from youth males (14.8%). Level of education was distinctly low; only 59% of the respondents had attained primary school education as their highest level while 13% had not attained any formal education. The highest respondents interviewed grew both sorghum and cowpea (57.8%) with cowpea being the least grown (7%) by households. The mode of planting mostly preferred by farmers was intercropping sorghum and cowpea (57.8%) while cowpea was the least grown as a monocropping (7%) by the farmers in the area. On addition, the type of farm input which was commonly used was manure (37.2%) followed by use of combination of fertilizer and manure (31.2%). But (17%) of the households never used fertilizer nor manure while inorganic fertilizers were least used (14.5%).

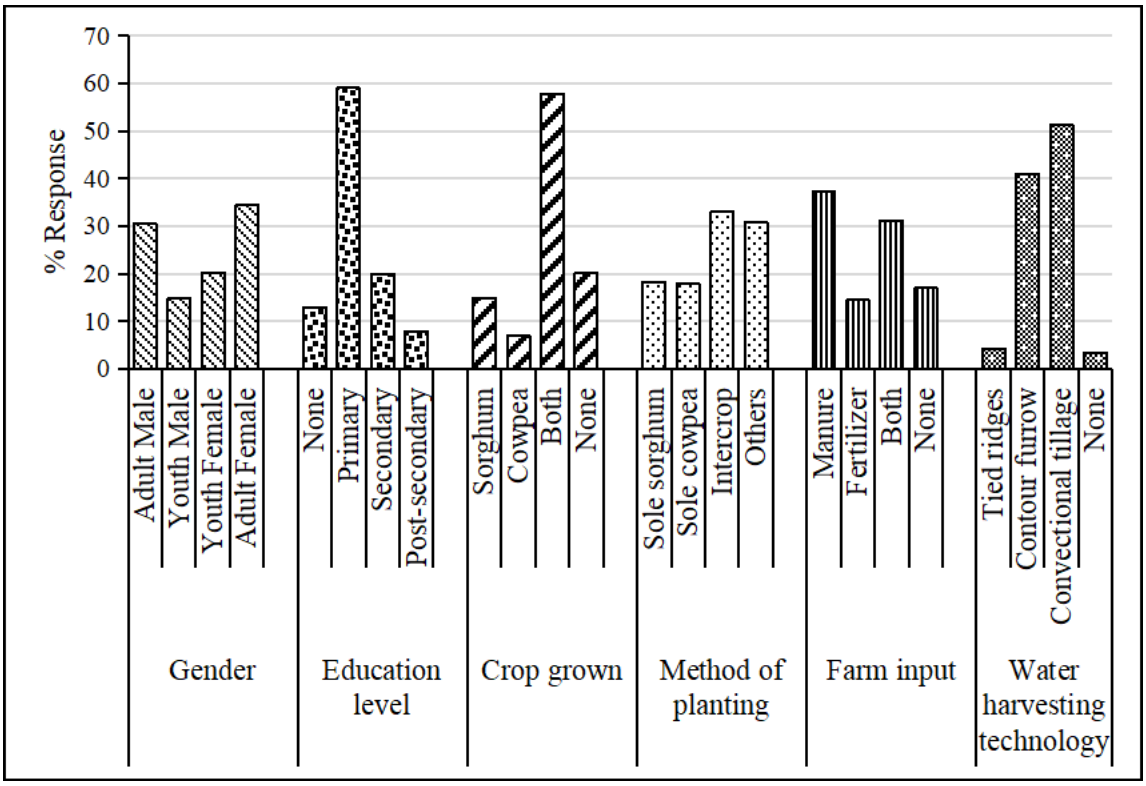

Figure 4.1: Distribution (%) of household's characteristics and on-farm management practices in Mariari site (n=351)

The results further indicated that 51.3% of respondents used conventional tillage (farmers practice) as a means of SWH technology method of land preparation while 3.4% of respondents were not using any of the technology on-farm. Tied ridging were the least used means of SWH methods with only 4.3% of the respondents using them on- farm. The respondents indicated that construction of contour furrows on-farm (41%) was as a result of type of land preparation methods (e.g. Oxen ploughing and donkey ploughing) being the most practiced means of land of preparation in the area with an intension of making furrows along the contours during planting.

The data showed that sorghum grain yields (t/ha) and farmers evaluation score on individual treatments were significantly and positively correlated (r=0.50, p<0.0001) (Table 4.17). There were 14 treatments which were ranked in "good" category, they included 8, 4 and 2 under Tied ridging, contour furrows and farmers practice SWH methods categories, respectively. The results further showed that they represented the highest producers in sorghum grain yields 2.5 –3.2 t ha^{-1} and were the most preferred by the farmers with a ranking mean score of 2.5–2.7, respectively, and they were significant different ($p>0.05$). However, the treatment under Tied ridging under monocropping system plus 20N+40P+M2.5 was the best yielding and received the highest preference by farmers at a mean score of 2.7. The grain yield of this system was 3.2 t ha^{-1}.

Table 4.17: Comparison of Farmers' Ranking of Treatments and Scientific Assessment of Sorghum Grain Yields at Mariari Site

Soil water harvesting	**Cropping patterns**	**Soil fertility amendment practices**	**Grain yield t/h**	**Biophysical data ranking**	**Mean score by farmers**	**Overall rating by farmers**
Tied ridging	Monocropping	20N+40P	2.1	29	2.0	Fair
Tied ridging	Monocropping	20N+40P+M2.5	2.7	2	2.6	Good
Tied ridging	Monocropping	40N+40P	2.2	15	2.4	Fair
Tied ridging	Monocropping	40N+40P+M5	2.5	8	2.5	Good
Tied ridging	Monocropping	C	0.9	31	1.4	Poor
Tied ridging	Monocropping	M5	2.9	2	2.6	Good
Tied ridging	Intercropping	20N+40P	2.5	8	2.5	Good
Tied ridging	Intercropping	20N+40P+M2.5	3.2	1	2.7	Good
Tied ridging	Intercropping	40N+40P	2.8	8	2.5	Good
Tied ridging	Intercropping	40N+40P+M5	3.0	2	2.6	Good
Tied ridging	Intercropping	C	1.0	31	1.4	Poor
Tied ridging	Intercropping	M5	2.8	8	2.5	Good
Contour Furrow	Monocropping	20N+40P	2.4	15	2.4	Fair
Contour Furrow	Monocropping	20N+40P+M2.5	2.5	2	2.6	Good
Contour Furrow	Monocropping	40N+40P	2.2	23	2.2	Fair
Contour Furrow	Monocropping	40N+40P+M5	2.3	23	2.2	Fair
Contour Furrow	Monocropping	C	0.8	33	1.3	Poor
Contour Furrow	Monocropping	M5	2.0	27	2.1	Fair
Contour Furrow	Intercropping	20N+40P	1.9	15	2.4	Fair
Contour Furrow	Intercropping	20N+40P+M2.5	2.6	2	2.6	Good
Contour Furrow	Intercropping	40N+40P	2.3	15	2.4	Fair
Contour Furrow	Intercropping	40N+40P+M5	2.6	8	2.5	Good
Contour Furrow	Intercropping	C	0.9	33	1.3	Poor
Contour Furrow	Intercropping	M5	2.8	8	2.5	Good
Farmers Practice	Monocropping	20N+40P	2.4	20	2.3	Fair
Farmers Practice	Monocropping	20N+40P+M2.5	2.2	27	2.1	Fair
Farmers Practice	Monocropping	40N+40P	2.5	20	2.3	Fair
Farmers Practice	Monocropping	40N+40P+M5	2.5	23	2.2	Fair
Farmers Practice	Monocropping	C	0.5	36	1.1	Poor
Farmers Practice	Monocropping	M5	2.6	2	2.6	Good
Farmers Practice	Intercropping	20N+40P	2.4	15	2.4	Fair
Farmers Practice	Intercropping	20N+40P+M2.5	2.2	20	2.3	Fair
Farmers Practice	Intercropping	40N+40P	2.4	23	2.2	Fair
Farmers Practice	Intercropping	40N+40P+M5	2.0	30	1.7	Fair
Farmers Practice	Intercropping	C	0.7	35	1.2	Poor
Farmers Practice	Intercropping	M5	2.7	8	2.5	Good
r=0.50						
N=351						
CV			37.8		36.1	
LSD			0.021		0.020	
*p*_value			<0.0001		<0.0001	

The standalone inorganic fertilizer treatments with soil amendment of 20N+40 P kg ha^{-1} and 40N+40P kg ha^{-1} farmers rated them in "fair" category except in Tied ridging-monocropping pattern alone (Table 4.17). This category recorded average sorghum grain yields ranging from 1.9 –2.5 t ha^{-1} with farmers ranking mean score of 2.0–2.4, respectively, and they were significantly different ($p<0.05$). The treatments with the lowest grain yield and farmers mean score of <1.0 t/ha and <1.4 were ranked in "poor" category, respectively. These treatments represented experiment "controls".

There was a highly significant relationship between the farmers gender and overall evaluation and ranking of treatment (Pearson X^2=46.4, $p<0.0001$) (Table 4.18). Therefore, the overall rating of treatments highly depended on farmers his/her gender. On average, the male and female adults recorded significantly the highest percentage and ranking mean score of >29% and >2.07 respectively, as compared to youth male and female. The results further indicated that there was a significant difference (p=0.004) on ranking of treatments between adults (male and female) and youths the (male and female).

Table 4.18: Farmers' Ranking of Treatments by Gender in Mariari Site

Gender	**Percentage (%) Score**			**Ranking by farmers**
	Poor	**Fair**	**Good**	**Mean score**
Male adult	29.4	36.6	36	2.07a
Female adult	29.7	39.1	37	2.08a
Male youth	28.8	34.2	32	2.03b
Female youth	28.8	35.6	33.8	2.04b
N=351				CV=38.8
X^2=46.4				LSD=0.024
*P*_value	<0.0001	<0.0001	<0.0001	0.004

There was a highly significant relationship between the farmer's education level and overall evaluation and rating of treatments (Pearson X^2=19.8, $p<0.0003$) (Table 4.19). Therefore, the overall ranking of treatments highly depended on farmer's education level. On average, for those who did not go to school and primary school recorded significantly the lowest percentage and ranking mean score of <39.8% and <2.04 as compared to secondary and tertiary scholars. The results further indicated that there was a significant difference (p=0.004) in the ranking of treatments between the farmers who did not and those who attained secondary education.

Table 4.19: Farmers' Ranking of Treatments by Education Level in Mariari Site

Education	Percentage (%) Score			Rating by farmers
	Poor	**Fair**	**Good**	**Mean Score**
None	21.8	31	38.5	2.03b
Primary	23.2	32.3	39.8	2.04b
Secondary	25.5	35.2	46	2.08a
Tertiary	26.3	33	43.8	2.07a
N=351				CV=38.8
X^2 =19.8				LSD=0.024
*P*_value	0.003	0.003	0.003	0.004

4.3.1 Farmer's Evaluation on Treatments Performance in Kirinyaga West Sub-County

In Kirinyaga West Sub-County, the results indicated that household characteristics of the respondents involved in the treatment evaluation were adult females (41.8%) followed by adult males (17.2%) (Figure 4.2). Unlike the result of youth males were (17.2%) with the least representative from youth females (11.1%). The level of education was distinctly higher in Kirinyaga West as compared to Mbeere West Sub-County. The level of illiteracy was lower with (>62%) who attained secondary school education. With the lowest number of respondents (1%) who did not attain formal education. The highest respondents interviewed grown both sorghum and cowpea (71.3%) and sorghum being the least grown (11.1%) by households. The mode of planting most preferred by farmers was intercropping sorghum and cowpea (46.3%) and this was closely followed by growing cowpea (32.8%) as a monocropping while sorghum was the least grown as a monocropping (9%). The highest type of farm input which was commonly used by respondents was use of both fertilizer and manure (55.7%) followed by use of manure (31.6%) while inorganic fertilizers were least used (7.8%). However, 4.9% of the households never used fertilizer nor manure.

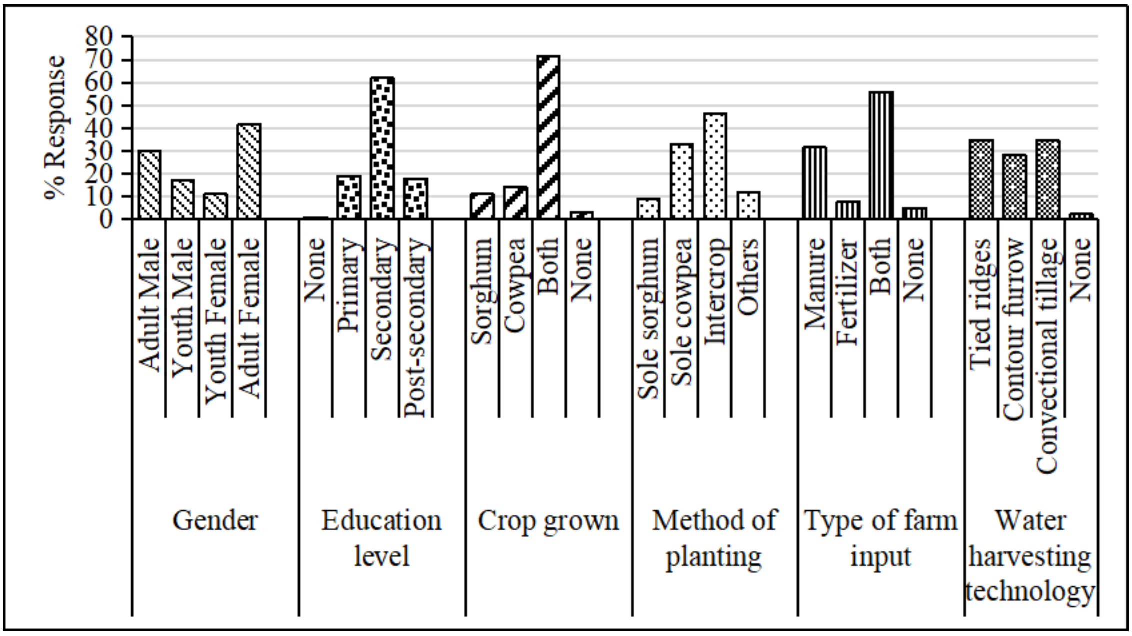

Figure 4.2: Distribution (%) of household's characteristics and on-farm management practices in Karima site (n=345)

Respondents indicated that they used both tied ridging and convectional tillage (34.7%) as means of SWH technologies on-farms (Figure 4.2). While 2.4% of the respondents did not use any of the SWH methods. The respondents indicated that construction of tied ridging on-farm was as a result of type of land preparation methods (e.g. on-farm water holding structures) as the most practiced means of land of preparation in the area. They make ridges with an intention of making water structures for holding rain-fed water or irrigation water for horticultural cultivation. This is a widely means of SWH methods practiced in the area.

There was a significant positive correlation (r^2=0.542, p<0.0001) between sorghum grain yields (t/ha) and farmers evaluation score on individual treatments (Table 4.20). There were 13 treatments which were ranked in "Good" category, these included 5, 4 and 4 under tied ridging, contour furrow and farmers practice SWH methods categories, respectively. The results further showed that these treatments had the best sorghum grain yields (2.2–3.3 t ha^{-1}) and they attracted the highest farmers preference with mean score of 2.5 to 2.9, respectively, and they were significant different (p<0.05). The treatment under tied ridging under monocropping system plus soil amendment of (20N+40P+M2.5) gave the highest yields and attracted the highest preference of farmers with grain yields of 3.3 t ha^{-1} and a mean score of 2.9 respectively and was highly ranked in 'good' category.

Table 4.20: Comparison of Farmers' Ranking of Treatments and Scientific Assessment of Sorghum Grain Yields at Karima Site

Soil water harvesting	Cropping patterns	Soil fertility management	Grain yield t/h	Biophysical data ranking	Mean score by farmers	Overall rating by farmers
Tied ridging	Monocropping	20N+40P	1.7	26	1.6	Fair
Tied ridging	Monocropping	20N+40P+M2.5	3.3	1	2.9	Good
Tied ridging	Monocropping	40N+40P	1.7	22	1.8	Fair
Tied ridging	Monocropping	40N+40P+M5	2.0	15	2.3	Fair
Tied ridging	Monocropping	Control	0.6	30	1.3	Poor
Tied ridging	Monocropping	M5	2.8	9	2.5	Good
Tied ridging	Intercropping	20N+40P	1.5	22	1.8	Fair
Tied ridging	Intercropping	20N+40P+M2.5	2.2	2	2.8	Good
Tied ridging	Intercropping	40N+40P	1.9	17	2.2	Fair
Tied ridging	Intercropping	40N+40P+M5	2	17	2.2	Fair
Tied ridging	Intercropping	Control	0.6	36	1.1	Poor
Tied ridging	Intercropping	M5	3.1	7	2.6	Good
Contour Furrow	Monocropping	20N+40P	2	17	2.2	Fair
Contour Furrow	Monocropping	20N+40P+M2.5	2.9	2	2.8	Good
Contour Furrow	Monocropping	40N+40P	1	22	1.8	Fair
Contour Furrow	Monocropping	40N+40P+M5	2.3	9	2.5	Good
Contour Furrow	Monocropping	Control	0.6	33	1.2	Poor
Contour Furrow	Monocropping	M5	2.3	9	2.5	Good
Contour Furrow	Intercropping	20N+40P	1.9	28	1.5	Fair
Contour Furrow	Intercropping	20N+40P+M2.5	2.9	2	2.8	Good
Contour Furrow	Intercropping	40N+40P	2.1	15	2.3	Fair
Contour Furrow	Intercropping	40N+40P+M5	2	20	2.1	Fair
Contour Furrow	Intercropping	Control	0.5	30	1.3	Poor
Contour Furrow	Intercropping	M5	2.2	7	2.6	Good
Farmers Practice	Monocropping	20N+40P	1.4	21	1.9	Fair
Farmers Practice	Monocropping	20N+40P+M2.5	2.4	9	2.5	Good
Farmers Practice	Monocropping	40N+40P	1.9	26	1.6	Fair
Farmers Practice	Monocropping	40N+40P+M5	1.4	22	1.8	Fair
Farmers Practice	Monocropping	Control	0.4	33	1.2	Poor
Farmers Practice	Monocropping	M5	2.5	9	2.5	Good
Farmers Practice	Intercropping	20N+40P	1.9	14	2.4	Fair
Farmers Practice	Intercropping	20N+40P+M2.5	2.6	2	2.8	Good
Farmers Practice	Intercropping	40N+40P	1.6	28	1.5	Fair
Farmers Practice	Intercropping	40N+40P+M5	1.5	30	1.3	Poor
Farmers Practice	Intercropping	Control	0.3	33	1.2	Poor
Farmers Practice	Intercropping	M5	2.8	6	2.7	Good
r=0.542						
N=345						
CV			55.3		40.00	
LSD			0.03		0.02	
*p*_value			<0.0001		<0.0001	

The standalone inorganic fertilizer treatments with soil amendment of 20N + 40 P and 40 N+40P kg ha^{-1} under monocropping and intercropped patterns were rated in "fair" category (Table 4.20). This category recorded an average sorghum grain yields (1.0–2.1 t ha^{-1}) with farmers ranking mean score of 1.5–2.4 respectively, and they were significantly different (p<0.05) from each other. The treatments with the lowest grain yield and farmers mean score of <1.0 t/ha and <1.4 were ranked in "poor" category represented experiment ("controls"), respectively, and they were significantly different (p<0.05) from treatments receiving external inputs.

Farmers gender and overall evaluation and rating of treatments were significantly correlated (Pearson X^2=22.6, p<0.0001). Farmers overall rating of treatments highly depended on his/her gender with a similar observation that they ranked treatments differently in the scale of poor, fair and good categories (Table 4.21). The male and female adults recorded significantly the lowest percentage and ranking mean score of <29% and <2.05 respectively, as compared to youth male and female. Ranking of treatments between adults (male and female) and youths (male and female) varied significantly (p=0.027) between the groups.

Table 4.21: Farmers' Ranking of Treatments by Gender in Karima Site

Gender	**Percentage (%) Score**			**Ranking by farmers**
	Poor	**Fair**	**Good**	**Mean score**
Male adult	29	32.7	36.2	2.05b
Female adult	28.1	31.7	36.1	2.04b
Male youth	31.1	33	37.8	2.08a
Female youth	32.2	33.4	38.5	2.1a
N=345				CV=40.1
X^2=22.6				LSD=0.02
*P*_value	0.0007	0.0007	0.0007	0.027

Farmer's education level and overall evaluation and rating of treatments were positively correlated (Pearson X^2=15.4, p<0.081) (Table 4.22). Farmers overall rating of treatments highly depended on his/her education level. On average farmers who attained secondary school education significantly recorded the highest percentage and ranking mean score of >32.2% and >2.03, respectively, as compared to those who did not and those who attained primary school education. The ranking of treatments between farmers who did not have primary education and those who had attained primary education as their highest education level was statistically similar ($p<0.05$). But ranking of treatments differed significantly ($p=0.054$) from those who attained secondary school education.

Table 4.22: Farmers' Ranking of Treatments by Education Level in Karima Site

Education	**Percentage (%) Score**			**Ranking by farmers**
	Poor	**Fair**	**Good**	**Mean Score**
None	30.3	31.3	31.9	1.99b
Primary	32.1	32.6	33.1	2.02b
Secondary	33.3	34.9	37.1	2.07a
Tertiary	32.2	33.7	36.5	2.05a
N=345				CV=40.1
X^2 =15.4				LSD=0.02
*P*_value	0.081	0.081	0.081	0.054

4.4 Cost Benefits Analysis of SWH Techniques and Soil Fertility Amendments Practices under Sorghum and Cowpea Productivity

4.4.1 Cost Benefits Analysis for Sorghum and Cowpea Production in Mbeere South Sub-County

The treatments significantly ($p<0.0001$) affected net benefit, BCR and return to labour (Table 4.23). TR-Intercropping 20N+40P+M2.5, TR-monocropping 20N+40P+M2.5, TR-Intercropping 20N+40P and FP-Intercropping M5 were the most profitable treatments with a net benefit USD 1,176.72, USD 1,140.55. USD 1,095.15 and USD 981.85 ha^{-1}, respectively. But there were only 3 treatments CF-monocropping 20N+40P, TR-monocropping 20N+40P+M2.5 and FP-monocropping 20N+40P+M2.5 which had BCR of USD 2.0, USD 2.33 and USD 2.53 with return to labour USD 3.3, USD 3.9 and USD 4.1 ha^{-1}, respectively. These treatments recorded a BCR of >2. The FP-monocropping 20N+40P+M2.5 was most superior with the highest BCR (USD 2.53) and return to labour (USD 4.1).

Table 4.23: Net Benefit, BCR and Return to Labour under Various Treatments in Mariari Site, Mbeere South Sub-County

Soil water harvesting	**Cropping patterns**	**Soil fertility amendment practices**	**Net benefit** (USD)	**BCR** (USD)	**Return to labour** (USD)
Tied ridging	Intercropping	20N+40P	1095.15ab	1.29bc	2.4bc
Tied ridging	Intercropping	20N+40P+M2.5	1176.72a	1.28bc	2.5bc
Tied ridging	Intercropping	40N+40P	855.45b	0.95cd	2.1c
Tied ridging	Intercropping	40N+40P+M5	844.12b	0.97cd	2.2bc
Tied ridging	Intercropping	Control	-116.71e	-0.29e	2.0c
Tied ridging	Intercropping	M5	615.41bc	0.68cd	1.8c
Tied ridging	Monocropping	20N+40P	588.09bc	1.27bc	2.5bc
Tied ridging	Monocropping	20N+40P+M2.5	1140.55ab	2.33ab	3.9a
Tied ridging	Monocropping	40N+40P	656.95bc	1.35bc	2.7bc
Tied ridging	Monocropping	40N+40P+M5	436.53cd	0.78cd	2.1c
Tied ridging	Monocropping	Control	143.63d	0.35de	1.4cd
Tied ridging	Monocropping	M5	596.59bc	1.24bc	2.5bc
Contour furrows	Intercropping	40P20 N	702.06bc	0.86cd	0.7d
Contour furrows	Intercropping	20N+40P+M2.5	836.16b	0.98cd	2.1c
Contour furrows	Intercropping	40N+40P	863.62b	1.10c	2.3bc
Contour furrows	Intercropping	40N+40P+M5	591.57bc	0.62cd	1.8c
Contour furrows	Intercropping	Control	-86.44de	-0.12d	0.9d
Contour furrows	Intercropping	M5	629.49bc	0.74cd	1.9c
Contour furrows	Monocropping	20N+40P	772.84b	1.96ab	3.3ab
Contour furrows	Monocropping	20N+40P+M2.5	801.69b	1.85b	3.3ab
Contour furrows	Monocropping	40N+40P	674.99bc	1.57bc	3.0b
Contour furrows	Monocropping	40N+40P+M5	478.84c	0.95cd	2.4bc
Contour furrows	Monocropping	Control	175.12d	0.50cd	2.8bc
Contour furrows	Monocropping	M5	603.20bc	1.42bc	1.5cd
Farmers Practice	Intercropping	20N+40P	602.90bc	0.89cd	2.0c
Farmers Practice	Intercropping	20N+40P+M2.5	723.45bc	0.92cd	2.1c
Farmers Practice	Intercropping	40N+40P	629.33bc	0.81cd	2.0c
Farmers Practice	Intercropping	40N+40P+M5	806.41b	1.08c	2.4bc
Farmers Practice	Intercropping	Control	-53.07de	-0.25e	0.7d
Farmers Practice	Intercropping	M5	981.85ab	1.26bc	2.5bc
Farmers Practice	Monocropping	20N+40P	666.52bc	1.83b	3.4ab
Farmers Practice	Monocropping	20N+40P+M2.5	822.51b	2.53a	4.1a
Farmers Practice	Monocropping	40N+40P	715.28bc	1.98ab	3.7a
Farmers Practice	Monocropping	40N+40P+M5	411.72cd	1.07c	2.6bc
Farmers Practice	Monocropping	Control	114.21de	0.40d	1.4cd
Farmers Practice	Monocropping	M5	705.02bc	1.97a	3.6ab
CV%			41.5	49.9	29.1
$LSD_{(0.05)}$			291.75	0.62	0.78
*p*_value			0.0001	0.0001	0.0001

Note: Treatments means having different letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea

The lowest net benefit, BCR (<1) and return to labour was recorded in treatments regarded as experiment "controls". The most superior treatment (CF-monocropping Control) in this category recorded return to labour, BCR and net benefit of USD 2.8, USD 0.50 and USD 175.12 ha^{-1}, respectively (Table 4.23). Treatments under monocropping patterns showed higher return to labour and BCR (USD 2.8 and USD 1.4 ha^{-1}) than those under intercropping system (Figure 4.3).

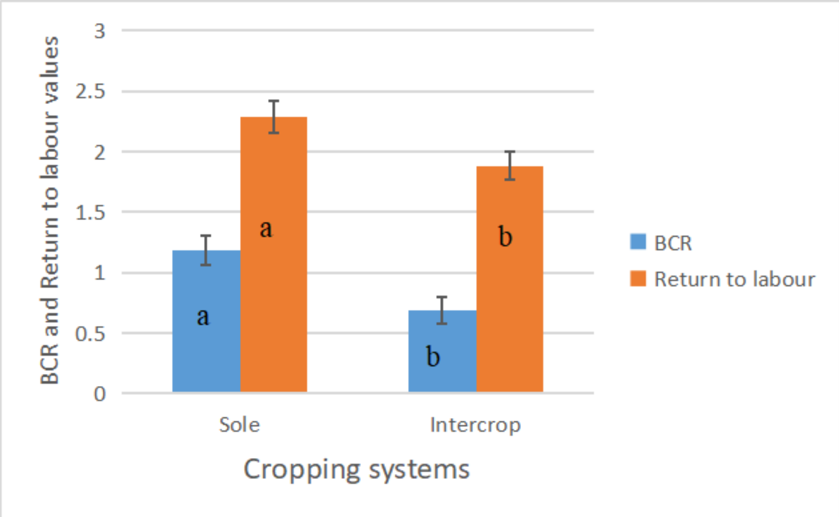

Figure 4.3: BCR and return to labour effect of cropping patterns in Mariari site, Mbeere South Sub-County

For water conservation methods, farmers practice generated significantly higher BCR and return to labour USD 1.2 and USD 2.5 per hector respectively, as compared to other SWH technologies (Figure 4.4). However, all the SWH methods had BCR of greater than 1.

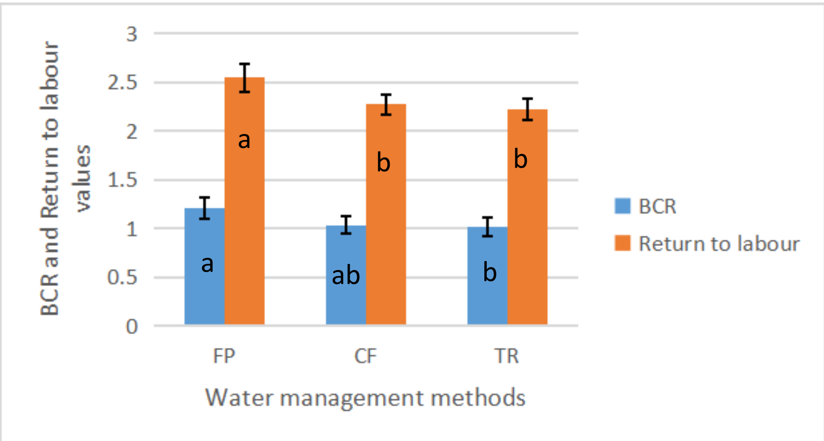

Figure 4.4: BCR and return to labour effect of SWH methods in Mariari site, Mbeere South Sub-County

The fertilizer combinations (40P20M2.5) had higher BCR and return to labour of USD 1.5 and USD 2.9 as compared to control which had USD 0.1 and USD 1.1 per hector, respectively. However, the treatment with fertilizer combination (40P20M2.5) was not different from 20N+40P, 40N40P and M5 (Figure 4.5).

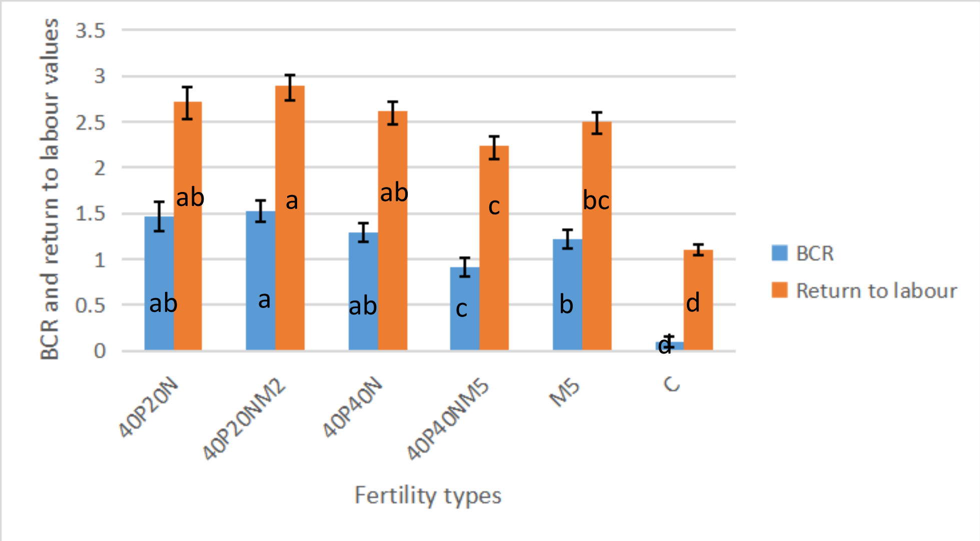

Figure 4.5: BCR and return to labour effect of soil fertility management options in Mariari site, Mbeere South Sub-County

4.4.2 Cost Benefits Analysis for Sorghum and Cowpea Production in Kirinyaga West Sub-County

The treatments significantly (p<0.0001) affected net benefit, BCR and return to labour (Table 4.24). TR-Intercropping M5, CF-Intercropping 40N+40P, TR-Intercropping M5, CF-Intercropping 40N+40P, TR-monocropping 20N+40P+M2.5 and CF-Intercropping 40N+40P+M5 were the most profitable treatments with a net benefit of USD 2,350.01, USD 2090.61, USD 2,042.67, USD 1,814.63, USD 1,763.48, and USD 1,676.66 per hector, respectively.

Table 4.24: Net Benefit, BCR and Return to Labour under Various Treatments in Karima Site, Kirinyaga West Sub-County

Soil water harvesting	Cropping patterns	Soil fertility amendment practices	Net benefit (USD)	BCR (USD)	Return to labour (USD)
Tied ridging	Intercropping	20N+40P	1353.40bc	1.56bc	2.7bc
Tied ridging	Intercropping	20N+40P+M2.5	1376.67bc	1.52bc	2.8bc
Tied ridging	Intercropping	40N+40P	1484.23b	1.64bc	2.9bc
Tied ridging	Intercropping	40N+40P+M5	1465.29b	1.49bc	2.8bc
Tied ridging	Intercropping	C	188.13cd	0.23cd	2.6bc
Tied ridging	Intercropping	M5	2042.67ab	2.27b	3.6bc
Tied ridging	Monocropping	20N+40P	999.21bc	2.22bc	3.6bc
Tied ridging	Monocropping	20N+40P+M2.5	1763.48ab	3.61a	5.4a
Tied ridging	Monocropping	40N+40P	1077.54bc	2.22bc	3.8b
Tied ridging	Monocropping	40N+40P+M5	500.45cd	0.89cd	2.2c
Tied ridging	Monocropping	C	88.08cd	0.22cd	1.2c
Tied ridging	Monocropping	M5	510.43cd	0.93cd	2.1c
Contour furrows	Intercropping	40P20 N	1117.26bc	1.37bc	1.2c
Contour furrows	Intercropping	20N+40P+M2.5	1814.63ab	2.13bc	3.5bc
Contour furrows	Intercropping	40N+40P	2090.61ab	2.46ab	3.9b
Contour furrows	Intercropping	40N+40P+M5	1676.66ab	1.82bc	3.3bc
Contour furrows	Intercropping	C	119.40cd	0.15cd	1.2c
Contour furrows	Intercropping	M5	933.43bc	1.10c	2.3c
Contour furrows	Monocropping	20N+40P	1257.39bc	3.19ab	4.8ab
Contour furrows	Monocropping	20N+40P+M2.5	727.63c	1.68bc	3.1bc
Contour furrows	Monocropping	40N+40P	946.26bc	2.20bc	3.8b
Contour furrows	Monocropping	40N+40P+M5	265.87cd	0.53cd	1.7c
Contour furrows	Monocropping	C	77.63cd	0.22cd	2.9bc
Contour furrows	Monocropping	M5	646.17c	1.52bc	1.2c
Farmers Practice	Intercropping	20N+40P	1445.88bc	1.94bc	3.2bc
Farmers Practice	Intercropping	20N+40P+M2.5	1398.95bc	1.78bc	3.1bc
Farmers Practice	Intercropping	40N+40P	1435.44bc	1.84bc	3.2bc
Farmers Practice	Intercropping	40N+40P+M5	2350.01a	2.77ab	4.5ab
Farmers Practice	Intercropping	C	-95.92d	-0.14d	0.9c
Farmers Practice	Intercropping	M5	1042.35bc	1.34bc	2.6bc
Farmers Practice	Monocropping	20N+40P	596.17cd	1.83bc	3.3bc
Farmers Practice	Monocropping	20N+40P+M2.5	1043.01bc	2.86ab	4.8ab
Farmers Practice	Monocropping	40N+40P	443.17cd	1.23bc	2.7bc
Farmers Practice	Monocropping	40N+40P+M5	1076.52bc	2.46ab	4.8ab
Farmers Practice	Monocropping	C	60.59cd	0.21cd	1.2c
Farmers Practice	Monocropping	M5	952.92bc	2.67ab	4.5ab
CV%			63	62.8	42.4
$LSD_{(0.05)}$			723.28	1.15	1.44
p_value			0.0001	0.0001	0.0001

Note: Treatments means having diffrent letters in the same column are statistically different ($p \leq 0.05$) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea

There were 12 treatments which were most superior with the highest net benefit (>946.26), BCR (>USD 2.13) and return to labour (>USD 3.5) ha^{-1} and they were significantly higher (P<0.05) than the rest of the treatments and they recorded a BCR of greater than 2 (Table 4.24). Treatment TR-monocropping 20N+40P+M2.5 and CF-monocropping 20N+40P were the most superior with the highest BCR of USD 3.61 and USD 3.19 and return to labor of USD 5.4 and USD 4.8 per hector, respectively. The lowest net benefit, BCR (<1) and return to labour was recorded in treatments regarded as experiment "controls".

CHAPTER 5: DISCUSSION

5.1 Crop Growth Parameters and Yields

The result in Table 4.1 & 4.2 indicated that sorghum crop height varied significantly in the 3 seasons in both study sites. The results further indicates that treatments did not differ significantly during the LR 2011 and LR 2012 seasons ($p>0.05$), but the treatments with the tallest plants differed significantly from the rest of the treatments over the study period. Higher sorghum heights were recorded during the SR 2011 and LR 2012 seasons compared to the LR 2011 season in both study sites. The heights of plants across treatments were mainly determined by seasonal rainfall distribution (Figure 3.2 and 3.4), thus high uniformly distributed rainfall led to relatively the tallest plants. These findings agree by Karuma *et al.* (2014) that plant heights are mainly proportional to soil moisture available during the crop vegetative development stage. The results further showed that monocropping sorghum had taller plants than intercropped sorghum at different weeks after planting. Unlike in Kirinyaga West, Intercropping recorded the tallest sorghum heights. This could be suggesting that soil moisture content is not a crop growth-limiting factor in medium potential area as compared to drier part of this study.

Generally, sorghum heights indicated that they were not related to the final grain yields as an effect of N and P fertilizer rates in Kirinyaga and Mbeere South sites. Similar results were observed by several authors (Razaq *et al*. 2017) that N is a crucial nutrient required for the vegetative development of plants. These results contradict Miriti *et al*. (2012), Mwende *et al*. (2019) and Karuma *et al.* (2014) findings that increased plant height for maize crop in an intercropping of beans was correlated crop's grain production. These authors argued that the maize stem could mobilize sugars from labile non-structural carbohydrates which translate to increased grain yields. Therefore, the maize stems could serve as the main source of increased as grain yields as compared to sorghum stems against longer term effects on final crop yield (Passioura and Angus, 2010). In the current study, sorghum produced little yields due to unevenly distributed rainfall during the growing period. The results are in agreement with Kenya Meteorological Department [KMD], (2013) that unevenly distributed rainfall at the onset of the season and dry conditions affects crop growth leading to crop failure or sub-optimal yields. Further, Kagwiria *et al.* (2019) reported that the main constraint for sorghum production was poor distribution of rainfall during the cropping season and field pests (especially birds) which can lead to 100% loss of the crop.

The study observed that sorghum intercropped with cowpea produced lower yields than sole cropped sorghum. This outcome for sorghum yields is in line with the findings on maize cowpea intercropping on nutrient competition resulting to reduced crop yields in Kenya (Mwende *et al*., (2019) and in southwest Nigeria (Saka *et al.*, 2018). Elsewhere, intercropping maize and cowpea reduced maize yields by 46–57% and cowpea by 9% due to competition for soil moisture (Jensen *et al*., 2003). According to Karuma *et al.* (2014), maize grain yields reduction in intercropped system with beans as compared to the monocropping was also contributed by interspecific soil nutrient competition in the intercrop system and there was no interspecific nutrient competition in a Monocropping system. Explaining the current findings, Baoua *et al.* (2021) and Nelson *et al*. (2018) established that intercropping cowpeas and a cereal in arid areas decreases the crop productivity due to competition for limited growth resources. But farmers commonly optimize farm resource utilization efficiency through intercropping to reduce risk of food productivity (Ngetich *et al.,* 2014a). Contrary observations by Mucheru-Muna *et al.* (2010) and Martínez-Mena *et al*. (2020) demonstrated that intercropped systems were associated with high utilization efficiency of growth resources compared to sole crop systems, leading to relatively higher production.

Generally, grain yields increased with time from the 1^{st} to the 3^{rd} season in this study. The reported yields for cowpea yields were < 2 t ha^{-1} in both study site. The crop were introduced as a legumes as they have ability to biologically fix atmospheric nitrogen planted as an intercropping of sorghum. The low cowpea yields reported could be due to competition for soil nutrients, water and light in the intercropping systems in drier part of this study. Similar findings have been reported by Woomer (2010) and Odendo *et al*. (2011) that bean yields in SSA are extremely low (<1 t/ha) due to declining soil fertility and commonly grown by small scale farmers who are resource-poor.

Soil fertility amendment practices had significant effects on sorghum and cowpea grain yields in both study areas in LR 2011, SR 2011 and LR 2012 seasons. By integration of minimal nutrient replenishment of organic inputs and mineral fertilizers more than 100% increase in sorghum and cowpea grain and biomass yields were recorded above experiment controls in both study sites. Laub *et al*. (2023) and Mwende *et al*. (2019) findings support the current study that it is realistic to increase cereal yields by incorporating organic inputs with inorganic N at lower application rates. As a result, Sanchez (2015) opined that access of both organic and mineral fertilizers should be prioritized in SSA instead of increasing access to inorganic fertilizers only. The N levels could have accelerated the conversion of rapidly synthesized carbohydrates into protein and to protoplasm (Kayuki *et al*., 2012). Also, similar results have been reported in this study that higher biomass and grain yields were recorded under half optimal rates of organic and inorganic fertilizers under different combinations of treatments. Farmers are guaranteed high returns on investment by micro-dosing sorghum with 20 kg N ha^{-1} in drier parts of Central Kenya, as shown in Ghana by Buah *et al.* (2012). The current findings also are in agreement with earlier studies (For example, Kibunja *et al.* (2010)) that water moisture and nitrogen are the most limiting growth resources in crop production systems in semi-arid lands of Kenya (Njeru *et al.*, 2010).

There was a consistency of higher grain, biomass and total dry matter yields results under Tied ridging-Monocropping system with addition of minimal application of synthetic fertilizers and manure inputs at half rate of 20N and M2.5 as compared to controls in both study sites. The soils are designed to release specific nutrients at different stages of cropping system in the season (Bindraban *et al*., 2015). This was an indication that soil nutrient supplement was a key requirement for improving soil fertility status in all the seasons in both study sites. These results corroborate Mugendi *et al*. (1999) and Gachimbi (2002) that soils require nutrient re-application seasonally from inorganic, organic inputs and incorporation of crop residue in the soil in farms in Central Kenya Highlands. In Mbeere South, similar observations where Tied ridging showed greater maize grain yields relative to zero input control (Ngetich, 2012; Mwende *et al*., 2019) and in Tharaka Nithi Sub-County Ndung'u *et al.* (2023), and Eastern Ethiopia (Araya and Stroosnijder, 2010).

However, there was no significant effects of SWH methods on sorghum and cowpea grain yields in medium potential areas in all the seasons. But in drier part of this study, there were significant effect of SWH and interaction effect of SWH methods*soil fertility management options on sorghum grain yields. This is an indication that SWH methods and ISFM practices played an important role in conservation of soil moisture content which led to increased sorghum yields in drier part of this study. This is probably because water is a limiting factor under arid conditions (Figure 3.2 and 3.4). The findings corroborate Miriti *et al*. (2012) and Mucheru-Muna *et al*. (2010) who observed that combination of SWH methods and organic sources crop yields in Eastern Kenya. These findings suggest that mixed crop-livestock systems could be crucial in supporting crop production SSA (Herrero *et al*., 2010). However, since good quality and sufficient quantities of manure is not always available to many smallholder farmers in SSA, soil fertility can be maintained through cereal-legume and forage rotations and intercropping (Namatsheve *et al*., 2020).

The results further indicated that treatments under tied ridging and contour furrows recorded the highest sorghum grain yields in both study sites. This could be attributed to lower than average and poorly distributed rainfall in the study sites (Figure 3.2 and 3.4), as they conserved more soil moisture as compared to conventional tillage/farmers practice. Soil moisture deficit is the most limiting factors to crop performance in dry areas of Kenya (Muindi, 2019). This could be improved in on-farm water management through SWH and may be pivotal in supporting smallholder farming systems in SSA (Biamah, 2005). Similar observations by Singh *et al.* (2015) and Mwende *et al*. (2019) have shown that tied ridging and contour furrows SWH methods in combination of external soil fertility amendment has potential to significantly increase crop production. Also, this agrees with other studies that reported SWH technologies that retain rainwater in situ in the farms for crops to be efficient in increasing crop productivity (Itabari *et al.*, 2004). The SWH techniques perform well under prolonged rainwater infiltration and retention, thus increasing soil moisture and soil moisture holding capacity like the tied and open ridges (Singh *et al.,* 2015).

Generally, sole cropped sorghum and cowpea had higher grain yields relative to their intercropped counterparts in drier part of this study. This could be as a result of crops competition for limiting soil nutrient resources. Cowpeas have high demand for soil nutrient and they usually exhibit interspecific competition in an intercropping system

(Kagwiria *et al.,* 2019). The consistency of increased crop grains, biomass and total dry matter yields in monocropping system in drier part of this study agrees with Kagwiria *et al.* (2019) observations that intercropping fields showed high competition for water and reduced sorghum and cowpea yields in Makueni County. Similar findings by Katsaruware *et al.* (2009) have shown reduction in crop yields in mixed stands and associated this to competition for available nutrients in intercropping compared Monocropping s. Increased sorghum and cowpea productivity could have been as a result of application of inorganic fertilizers that lead to increased crop residue contributing to high biomass productivity (Fofana *et al*., 2005; Mwende *et al*., 2019). The crop residue improves soil biophysical characteristics which improves water use efficiency for crop productivity (Fofana *et al*., 2005).

5.2 Soil Chemical and Physical Properties

5.2.1 Effect of Treatments on Soil Chemical and Physical Elements

Low soil pH levels were recorded at the beginning of the study. The low pH levels are usually common in soils with high contents of Hydrogen and Aluminium ions in the medium. The high levels affect the release and availability of major nutrients to growing crops. Mugendi *et al*. (2010) observed significant decrease in soil pH can result from increased solubility of Fe, Al and Mn oxides resulting in low P uptake by the growing crops. Soil pH influences soil nutrients interactions, thus regulating their solubility and in the soil solution for crop uptake (Panhwar *et al*., 2016). The low soil pH levels could have been caused by longtime continuous cultivation practice and excessive use of phosphate fertilizers (Kimani *et al.,* 2007).

There was a significant increase in soil pH levels at the end of the study period in all the manure added treatments (t-test, $p<0.05$). This may suggest that addition of manure increased soil pH and decreased soil exchangeable acidity. The pH of the manure used was >9.24 (Table 3.2). A possible explanation to this observation could be that alkaline levels manure contributed to reduction of Al^{3+} (Kisinyo *et al*., 2012) and H^{+} ions in the soil. Elsewhere, farmyard manure application increases soil pH and soil organic carbon (Mtangadura *et al.,* 2017). The reduction is due to aluminum precipitation or formation of chelates on organic colloids or by complexation by organic acids (Mucheru-Muna *et al.*, 2014). A possible explanation to this observation could be that the pH increment in manure treatment could also be explained by high content of basic cations because processes that increase the concentration of basic cations in the soil lowers soil acidity (Kibet *et al.,* 2023; Mugwe *et al.*, 2009a).

Conversely, manure probably added exchangeable cations in the exchangeable soil that replaced the acidic cations. The results further indicated that soil pH increase could be as a result of addition of manures. Similar findings by several authors (Kheyrodin and Antoun, 2012; Mwasyika *et al*., 2018; Msanya *et al*., 2016) are in agreement that manure with high pH level has ability of releasing essential crop nutrients either directly or indirectly for crop growth. Authors also observed that manure increases soil pH levels when it is applied in the soil continuously over the season and it increases soil nutrients availability for better crop growth. The manure or standalone added treatments had significant increase in soil total N and C above the controls at the end of the study period in both sites. This could be as a result of addition of SOC by addition of manure. The findings are in agreement with Muindi et *al.* (2017) and Kiboi *et al.* (2019) that inorganic and organic inputs improved soil mineralization by enhanced maize crop performance and yields.

There was a significant increase of Calcium, Phosphorous, Magnesium, and Potassium except in the experiment "controls" at the end of study period. A possible explanation could be decomposition of SOM that contributed to increase amount of Ca^{2+}, Mg^{2+} and K^{+} amounts in soils as compared to experiment "controls". Similar findings by Muindi *et al.* (2017) have shown that an increase in exchangeable basic cations was recorded following application of manure which contributed to an increase in soil pH by contributing to hydroxyl ions and reducing the amount of exchangeable aluminium in acid soils. In terms of contributing to soil properties, treatment with optimal manure addition of (M5) showed superiority as compared to inorganic related treatments especially in relation to increasing pH, exchangeable Ca, total N and C in all the treatments except experiment "controls".

The increase in soil exchangeable Mg in Mariari and Karima study site, probably was as a result of nutrient mineralization in the soil. These findings are in agreement with those of Escobar and Hue (2008) that by addition of manure increased available Mg in the soil. Explanation for this could be the high acidity and low levels of Nitrogen and Phosphorous major nutrients at the beginning of the season was as a result of removal of nutrients by continuous growing crops , frequently use of ammonium nitrogen rich fertilizers, leaching of (Ca^{2+}, Mg^{2+}, K^{+}) exchangeable cations and high concentration of Al. There was an observed general trend of low P amount in plots under manure addition as compared to fertilizer treatments at the end of the experiment and this could be due to low amount of P levels in farm yard manures (Karuma *et al.,* 2019).

The results further recorded a significant increase (t-test, $p<0.05$) of major elements at the end of the experimentation period in relation to all experiment "control" and this affected of sorghum and cowpea yields respond to an external input addition of N, P and manure in both sites. This suggest that other factors in the play could have contributed to below optimal yields (Karuma *et al.,* 2019), these may include soil micronutrient deficiency. Additionally, the low levels of exchangeable bases could have been caused by "nutrients mining". Musanya *et al.,* (2016) observations are in agreement with findings that soils are generally have low or medium concentration of total N, organic matter, pH and crop available P and they may exhibit nutrient imbalance due to Ca, Mg, TEB and K rations.

5.2.2 Effect of Treatments on Soil Moisture Content Measurement

The soil water content measurement levels- were higher during the initial stages of measurements at two-WAP, four-WAP and six-WAP as compared to other intervals during all the seasons. This could be due to low rainfall distribution towards the crop physiological maturity stage (Figure 3.2 and 3.4). The overall soil water content was dependent on seasonal rainfall amounts and patterns of distribution during the season (Table 4.13, 4.14, 4.15 & 4.16). The lower the seasonal rainfall, the lower the soil water moisture for instance, SR 2011 had relatively low SWC measurements at every 2 weeks after planting (2 WAP) interval as compared to (LR 2012) which had high rainfall amount during the seasons.

The treatments with contour furrow and Tied ridging with soil fertility management options 20N+40P+M2.5, 40N+40P+M5 and M5 contained higher SWC as compared to inorganic fertilizer alone treatments in both study sites. Similar results have been reported in Agbede (2010) comparing zero and conventional tillage, Zhang *et al*. (2018) in China and in Zimbabwe (Mupangwa *et al*. 2012) reported that mulching and tillage system had better soil water conservation compared to conventional system during the seasons that had below average rainfall. These authors reported that CA- based practices improve soil water retention (Mutuku *et al*., 2020; Mupangwa *et al*., 2017).

Tied ridging conserved more SWC and was higher during the initial stages of measurements at two-WAP, four-WAP, six-WAP and eight-WAP relative to other intervals towards the end of the season in both study sites. Tied ridging is one of the most proposed means of on-farm rain SWH structures. But a decrease and the lowest SWC was recorded in treatments regarded as experiment "controls". The ability of Tied ridging conserving more soil moisture content throughout the seasons was also reported relative to other SWH methods in both study sites. A possible explanation was as a result of low rainfall distribution towards the end of the season (Figure 3.2 & 3.4). Similar results have been reported by Kiboi *et al.* (2019) and Ndegwa *et al*. (2023) who observed increased soil moisture conservation under Tied ridging as a result of ridges ability to conserve soil moisture content in Mbeere South sub-county. Furthermore, similar observations have been reported by several authors that Tied ridging are efficient in conservation of soil water content as compared to farmer practices (Miriti *et al.*, 2012; Ngetich *et al*., 2014b). Similar observations are also in harmony with Okeyo *et al*. (2014) in Central Kenya Highlands and Bertol *et al*. (2017) in Ghana that Tied ridging conserves more soil moisture content as they have ability to retain water in the ditched for a while and subsequently reduces soil nutrient losses across the season. The ability of Tied ridging to maintain more soil water also depended on the soil type, Cropping patterns and farm use practices (Ndegwa *et al*., 2023).

The results further demonstrated that treatments that had inorganic fertilizer application alone performed poorly on SWC during the two seasons in both study sites possibly due to high soil moisture uptake rates by the crop. Application of mineral fertilizers improves crop growth and development leading to declining soil moisture content from uptake by the crops (Deng *et al.*, 2006). Similar observations are reported in Mugendi *et al.* (2012) and Bindraban *et al.* (2015) where inorganic fertilizers contain nutrients which are highly soluble for crop utilization by increasing the crop demand for SWC. These findings by authors are also in conformity with those of Ngetich (2012) that application of inorganic fertilizer increased soil water use efficiency and evapotranspiration rates. This also supported observations by Steduto *et al.* (2009) that increased crop transpiration accelerated soil moisture diminution rate. Similar results of faster soil moisture depletion accelerated soil moisture utilization and improved crop growth under mineral fertilizer treatments (Oduor *et al.*, (2021).

The results further indicated that control treatments under normal farmers practice/conventional tillage recorded a decrease and the lowest SWC during the 2 seasons in both study sites. A possible explanation could be as a result of no external soil nutrient replenishment was added in these treatments leading to a decrease in SWC measurement throughout the seasons. Liu *et al*. (2010) In China, documented soil moisture stress in minimal tillage systems. The low SWC in the current study could be attributed to limited SOC in the no input treatments regarded as experiment "control". The same observation was also made by Kiboi *et al.* (2019) that the experiment zero-inputs controls consistently recorded low soil moisture relative to experimental treatments. A possible explanation is that tillage practices exposes soil leading to high soil moisture losses.

However, treatment with manure application of 40N+40PM5, M5 and 20N+40P+M2.5 recorded higher SWC as compared to stand alone inorganic fertilizers and experiment "controls ". A possible explanation could be due to increased soil organic carborn (SOC) derived from incorporation of manure into the soil. Studies by authors Enfors *et al.* (2011) and Brar *et al.* (2015), who found that soil organic carbon increases soil porosity and this increases soil water holding capacity. These results are also in conformity with Kolawole *et al.* (2014) that improved soil structure increases soil organic carbon amount by enhancing soil infiltration rate by improving soil water content availability to growing crops. Similar results by various authors Oduor *et al.* (2023) and Kiboi *et al.* (2019) they also been reported that manure added treatments increased soil moisture conservation and could be due to hastened integration of organic inputs into the soil. Binds microaggregates into macro-aggregates particles, thus improving soil water holding capacity (Jien *et al.* (2013). Findings in Mutuku *et al.* (2020) that reported that organic inputs such as manure and crop residue retention increased the ability of soil to store more moisture.

The Monocropping system of sorghum recorded higher SWC in both study sites. This was contrary for sorghum and cowpea Intercropping production in dry areas to what was reported by Sibomana, (2016) that maize-bean Intercropping provided greater ground cover and conserved more SWC, but findings indicated that sorghum and cowpea Intercropping systems created competition for soil moisture in drier areas as compared to Monocropping which conserved more SWC in Mbeere South Sub-County. The findings corroborate those of Karuma *et al.* (2014) that the intercropping systems hold less content due to high crop density leading to higher soil water content utilization by growing crops in an intercropping system.

5.3 Farmers Evaluation on Treatment Performance

Majority of the farmers with (57.8%) and (46.3%) grow sorghum plus cowpea as an intercropping in Mbeere South and Kirinyaga West respectively (Figure 4.1 & 4.2). A possible explanation could be that majority of farmers prefer intercropping cereals and legumes together in case of one crop fails there is an alternative crop for food security. Kagwiria *et al*. (2019) noted farmers preferred growing sorghum and cowpea as an intercrop as a means for food diversification of household diet in Makueni County.

The results (Table 4.17 & 4.20) showed a highly significant positive correlation ($r>0.5$, $p<0.0001$) between sorghum grain yields (t/ha) and farmers evaluation score on individual treatments. This implies that farmer's evaluation score of treatments was strongly correlated to sorghum grain yields. An explanation for this could be that treatments which recorded highest grain yields attracted the highest farmers preferences score and ranked in "good" category and vice versa. Similar observations by Cornelis *et al.* (2019) and Adeyolanu and Ogunkunle (2016) have also shown that farmers score was strongly correlated to famers evaluation on soil characteristics. The results of this study showed a strong relationship between scientific assessment of sorghum grain yields and farmer evaluation score on individual treatment scores in both study sites.

Farmers consistently rated 14 and 13 treatments with minimum nutrient replenishment regarded as high producers with grain yields ranging (2.5 Mg/ha to 3.2 Mg/ha) and (2.2 Mg/ha to 3.3 Mg/ha) in Mbeere South and Kirinyaga West respectively. They were overall rated in "good" category by farmers in both study sites. The highest producers overall rated as "good" by respondents received half optimal application rate of 20N+40P+M2.5. A possible explanation could be that minimal nutrient replenishment was a key requirement for increasing sorghum and cowpea production in both study sites. Similar observations have been reported by several authors that nutrient replenishment from organic and inorganic sources is a requirement for increasing crop productivity in Central Kenya Highlands (Gachimbi, 2002; Mugendi *et al*., 2010; Njeru *et al*., 2013b). Similarly, studies by Njeru *et al*. (2013a) and Wawire *et al.* (2021) also show that smallholder farmers can identify soil fertility indicators visually on crop physiological traits and yield production and therefore farmers evaluated all the treatments and their ranked them in terms of categorizing them in relations to their biophysical scientific production levels.

However, SWH technologies and ISFM practices improved soil moisture retention and enhanced sorghum productivity and were highly rated by the farmers in both study sites. Similarly Kiboi *et al*. (2019) reported that soil fertility management options were closely related to the soil's water retention capacity and enhanced maize productivity. The results on farmer's evaluation further indicated that the highest ranked treatments as "good" were the Monocropping s corresponding to higher grain yields (>2.0 t/ha) as compared to intercropping system. A possible explanation for this could be that cowpeas possess extensive rooting system, and they exhibit interspecific competition when intercropped. As a result, intercropping reduces crop yields (Katsaruware *et al.*, 2009).

Sorghum-cowpea intercrop lowered sorghum yields and this determined farmer's rating The observations are in agreement with Jensen *et al*. (2003) findings that intercropping maize and cowpea lead to soil moisture competition and lowered crop yields. Intercropping maize and cowpea is also documented to have affected the final maize yields Miriti (2011). Alternatively, this could be as a result slow release of nutrients from treatments which were manure added with majority rated in "fair" category. It has been reported in other studies that manure requires a number of seasons to undergo full decomposition process to meet optimal nutrient requirements by crops (Naudin *et al*., 2010). Thus, the results show clear correlation between farmer's perception and crop productivity.

The treatments classified as experiment controls were ranked in "poor" category by the farmers and they were the lowest producers. The treatments under farmers practice/conventional tillage intercropped with sorghum and cowpea were the least rated by the farmers in 'poorly' category recording the least grain yield (<0.31 t/ha). These findings are supported by Miriti *et al*. (2012) and Mugwe *et al*. (2009b) – continuous cultivation without nutrient replenishment leads to nutrient depletion contributing to reduce crop production. However, according to Demelash and Stahr (2010) labour intensiveness, scarcity of labourers and dynamics in land ownership remain barriers to the uptake of soil and nutrient management practices in smallholder systems. Therefore, appropriate land management practices can be improved through development of suitable agricultural technologies for Mbeere South and Kirinyaga West Sub-Counties.

The results (Table 4.18, 4.19, 4.21 & 4.21) further indicated that there was a significant relationship between the farmers gender and education level on overall ranking of treatment (Pearson $X^2>15.4$, $p<0.0001$). This meant that overall rating of treatments highly depended on his/her gender and education level in both study sites. Similarly, Mugwe *et al.* (2007a) reported a significant relationship between farm management categories adopters and non-adopters by gender on soil fertility replenishment in Central Kenya Highland. The results they are also in agreement with Bett (2004) finding that higher education influences decisions making because professionals are able scrutinize and evaluate on technical information on technologies accessed was significantly influenced by age and level of education of the household head in semi-arid Eastern Kenya.

The findings of the current study showed similar observations that there was a significant difference between farmers who attained secondary education and those who either did not or attained primary school education on treatment evaluation in both study sites. Therefore, farmers ranking of technologies highly depended on gender and education level in both study sites. These farmers could be used in future by agricultural extension services, researchers and policy makers in decision making on crop performance evaluations in Central Kenya Highlands. The results are in line with results by Ondedo *et al.* (2010) that farmers' subjective knowledge has a clear role in complementing scientific knowledge and is an important entry point for research and dissemination agencies in designing and implementing appropriate soil fertility management practices.

5.4 Cost Benefit Analysis

The findings from the Cost Benefit Analysis results (Table 4.23 & 4.24) showed that various treatments were costed to be able to get the value for sorghum and cowpea grains yields versus labour cost for production in both study sites. Based on this analysis, the recommendation to farmers has been concluded by considering profitability derived from individual treatments. The results indicated that FP-monocropping 20N+40P+M2.5 was most superior treatment with the highest BCR and return to labour of (2.53 and 4.1) and (2.86 and 4.8) in Mbeere South and Kirinyaga West respectively. A possible explanation could be that farmers practice/conventional tillage under Monocropping system with minimum soil nutrient replenishment was more beneficial and highly recommended for adoption by farmers in both study sites. Similar observations have been reported by FAO (2008) and that technologies with the highest net benefits, return to labour and BCR above 2 could be most and highly proposed for recommendation to farmers for adoption.

The results have identified 3 and 12 treatments in Mbeere S. and Kirinyaga W. respectively, with the highest net benefits, return to labour and BCR greater than 1in both study sites. An explanation for this could be that also these treatments could be recommended for adoption to farmers as a break-even point has been reached as it determines the cost of recovery of any new farming technology. Similar findings by Karuma *et al.* (2020) and Kamanga *et al.* (2010) have reported that treatments with BCR (>1) means that the cost of investment of sorghum and cowpea production has been recovered from the benefit realized. Additionally, the cost of recovery in any new farming system, a break-even point is realized when a Benefit Cost Ratio of 1 is reached. Only a few selected treatments had a BCR of above 2 in both study sites. A technology with a BCR above 2 is considered the minimum requirement for any new farming technology to be recommended for adoption to smallholder farming systems. (FAO, 2008; Ronner *et al.,* 2016). However, the treatments regarded as controls were unable to reach the minimum requirement of BCR (>1) due to lack of investments on either inorganic or organic inputs resulting to low financial return. An explanation for this could be due to very low crop yields reported in experimental controls in both study sites. Similar results have been reported by Mucheru-Muna *et al*. (2021) and Oduor *et al*. (2021) that farmers lack resources to invest in organic and inorganic inputs for nutrient replenishment to increase crop productivity.

The findings have demonstrated that combination of minimal addition of organic and inorganic inputs (40P20M2.5) rate had highest net benefit, return to labour and a positive BCR (>1) as compared to experiment controls. This was as a result of higher increased productivity of sorghum and cowpea which were recorded in these treatments. These results are similar with Denise and Meike (2020) observation that soil fertility amendment practices resulted in increased labor productivity and financial returns. The observations are also similar with those of Mutegi *et al*. (2012) and Mucheru-Muna *et al.* (2014) who reported that combination of *Tithonia diversifolia* plus inorganic fertilizer together attracted higher net benefits, BCR and return to labour as compared to application of monocropping fertilizers and control treatments. This study has reported that integration of minimal addition of external inputs on sorghum and cowpea productivity is a feasible investment with better financial returns amongst the smallholder farmers of Mbeere South and Kirinyaga West Sub-Counties.

Karuma *et al*. (2020) and Mugwe *et al.* (2007b) highlighted similar observations that integration of organic and inorganic fertilizers improved soil nutrients release by increasing crop yields consequently higher financial returns realized. The findings explain that minimal application of manure and synthetic fertilizers at half optimal rates recorded higher net benefit, BCR and return to labour than the recommended optimal rate of fertilizer (40N+40P+M5). Similar results were also reported on higher return to labour by combination of organics and inorganics inputs as compared to experiment controls (Mucheru-Muna *et al*., 2007; Muriuki, 2009). Also, similar results on higher economic returns have been reported in various studies on various soil amendment practices and SWH techniques (Hobbs *et al.*, 2011; Olarinde *et al.*, 2012).

The results have also demonstrated that Monocropping s significantly performed better with higher net benefit in low potential areas (AEZ LH3) as compared medium to high potential area (AEZ UM4) in Mbeere South and Kirinyaga West Sub-Counties, respectively. This could be as a result of previously reported higher sorghum and cowpea yields in this study. Explanation for this observation could be due to intra-specific soil nutrient mining posed by Intercropping sorghum and cowpea in production systems as compared to maize legume intercropping. Contrary, results by Zerihun *et al.* (2014) and Karuma *et al.* (2016) have shown that an intercropping of maize and bean had better financial returns with land equivalent ratios (>1) which explains the advantage of intercropping over monocropping patterns.

Despite the reduced yields recorded in intercropping patterns in drier part of this study, Intercropping could have resulted in increased crop yields of both crops but resulted to lower economic returns. Matusso *et al.* (2014) reported similar observations that intercropping resulted to higher crop yields which determined economic return. The same finding has also been reported by Seran and Brintha (2010) who reported that intercropping resulted to higher economic returns than monocropping patterns. Rusinamhodzi *et al.* (2011) also reported intercropping maize legumes minimizes the level of crop failure and increases land equivalent ratio as means of food security initiative.

Conventional tillage (FP) performed better and generated significantly higher return to labour and BCR as compared to other SWH techniques. This could be associated with the higher labour demand for construction of contour furrows and tied ridging by increasing labour for productivity in drier part of this study. These findings agree with Miriti (2012) who reported that tied ridging produced higher maize grain yields, but they were not economically viable due to intensive labour incurred during construction of ridges. Similar observation by Denise and Meike (2020) reported that higher labor demand could lead to increased labor of productivity in any farming systems.

SWH methods and cropping patterns did not show any significant differences on BCR and return to labour in wet part of this study. A possible explanation is that either of the SWH methods and cropping system could be recommended to farmers for adoption. This was due to evenly rainfall distribution in medium potential areas and there was no need for construction of SWH methods as compared to dry areas of this study. Bayu *et al*. (2012) obtained similar results where that tied ridging performance was determined by various factors such as soil fertility management options and rainfall distribution patterns in cropping season on crop yields.

The experimental controls recorded a significantly lower labour cost of production, but they resulted in low crop yields (Figure 4.5). However, the labour costs were significantly more in the treatments which received optimal rates of combination of organics and organics fertilizers followed by half optimal rates which recorded higher crop yields. On the other hand treatments which received organic fertilizer alone recorded higher labour cost compared to control in both sites. A possible explanation for this observation could be as a result of increased crop yields which determined the economic returns (output) of any enterprise. These observations by Mucheru-Muna *et al*. (2007) and Chappa *et al*. (2023) are in agreement that experiment controls recorded a significantly lower non-labour cost as compared to organics, organics + fertilizer and monocropping fertilizer treatments as they recorded higher crop yields.

CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter covers the summary of the findings, conclusions drawn from the findings and finally the recommendations. The results and recommendations of this study, areas for further research are also outlined.

6.2 Summary of the Findings and Conclusions

The results have demonstrated that selected SWH and integrated soil fertility amendment practices are key requirements for sorghum and cowpea production in Central Highlands of Kenya. The finding of this study showed consistency of higher grain, biomass and total dry matter yields results under tied ridging-Monocropping patters with addition of minimal application of synthetic fertilizers and organic inputs at half rate of 20N and M2.5 as compared to controls in both study sites. The study further showed that intercropping sorghum with cowpea reduced sorghum yields as a result of interspecific competition in intercropping pattern in drier part of this study and vice versa for medium potential areas. The findings also suggest that only low-input practices that are recommended for adoption through diversification of known crop in these areas.

The results showed that incorporation of manure improved the soil pH and soil water holding capacity. The findings further indicated that SWH methods, integration of soil fertility amendment practices and cropping patterns played a major role in soil moisture content increase which led to increased sorghum and cowpea production.

The results further demonstrated that tied ridging and monocropping pattern conserved substantive higher SWC throughout the season in drier parts of the study and vice versa for medium pontential areas. The study indicated that under low rainfall distributions, the tied ridging-monocropping pattern under manure amendment options was an efficient in soil moisture conservation even when the low rainfall distribution are below expectations translating to high grain yields in drier parts of this study. This study also indicated that manure application of 40N+40PM5, M5 and 20N+40P+M2.5 recorded higher SWC as compared to stand alone inorganic fertilizers and experiment "controls treatments. Therefore, this suggests to farmers should have management alternatives to overcome the problem of rainfall distribution as a cause of recurring climate change in Kenya and in the whole World.

The respondent results based on farmers treatment ranking, demonstrated that smallholder farmers' knowledge can provide a consistent treatment evaluation (ranking of treatments) as compared to biophysical data (actual crop yields). The findings demonstrated that farmers overall rating of treatments highly depended on his/her gender and education levels. Therefore, either gender at any level of education could be used by agricultural extension services, researchers and policy makers on decision making to evaluate other related scientific work in these study areas.

The results reported in the study on economic data demonstrated a clear evidence that there is need to incorporate low-input technologies on sorghum and cowpea productivity in drier parts of Central Kenya Highlands. It was concluded that there are significant variations in the value of net benefits from the different SWH methods, cropping system and soil fertility management practices combinations. A key finding of this study is that conventional tillage (FP) under Monocropping produced better returns on the money invested with minimal nutrient replenishment for producing improved sorghum and cowpea productivity, than with farmers conventional way (traditional practice of no fertilizer input) in both study sites. On the other hand, the results concluded that any of the SWH methods, either under monocropping or intercropping could be suitable for recommendation to farmers for adoption in medium potential area of this study.

6.3 Recommendations

i. Tied ridging are recommended for use by farmers to increase sorghum and cowpea productivity in Mbeere South Sub-Counties especially during low-rainfall distribution seasons.
ii. There is need for smallholder farmers to adopt low input in conjunction with appropriate SWH technologies on sorghum and cowpea productivity in Central Kenya Highlands.

iii. Smallholder farmers could be used in future by agricultural extension services, researchers and policy makers in decision making regarding crop performance ranking process in Central Kenya Highlands.

iv. It is economically viable to recommend conventional tillage (FP) under sorghum monocropping-pattern with minimum soil nutrient replenishment of 20N+40P+M2.5 to farmers in drier part of this study.

v. There is need for researchers and development actors to take scientific findings into consideration for effective partnerships with farmers for integrated soil fertility amendment practices in Central Highlands of Kenya.

vi. There is need to continually review farmers' recommendations based on past agronomic experiments, in the light of the present (and future) economic circumstances. This could be considered by CBOs, NGOs and EABL as an alternative food security initiative towards climate change mitigation in drought prone areas of drier parts of Central Kenya Highlands.

vii. There is need for structural, educational and intentional awareness creation on incorporation of organic inputs in our faming systems as the benefit will be realized in a long term period.

6.4. Areas for Further Research

i. There is need to examine further the interaction effects of various on-farm SWH methods on cowpea monocropping pattern and calculation of land equivalent ratio (LER) as a land productivity parameter for land use efficiency.

ii. There is need to explore further the various N loses paths under sorghum production system under different legumes cropping patterns for both optimal and economical use and minimization of its losses to the environment during the season.

iii. There is need to replace conventional urea in this study with ^{15}N labelled urea and monitor Nitrogen Use Efficiency (NUE) on sorghum and cowpea productivity in Mbeere South and Kirinyaga West Sub-Counties.

iv. There is need to explore long-term effect of SWH methods in various Agro-ecological zones so that more accurate generalizations can be concluded regarding suitable conditions required for sorghum production.

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APPENDICES

APPENDIX I: PHOTO SHOWING CROP HEIGHT MEASUREMENT

Plate 3: Sorghum heights measurement in various treatments using a tape measure

Appendix II: Photo Showing Soil Sampling Process for Diviner 2000 Calibration

Plate 4: Soil sampling process for bulk density measurement in a profile pit for Diviner 2000 calibration

Appendix III: Key Informants Interview Checklist for Farmers' Crop Evaluation Questionnaire

Theme: To evaluate farmer's perceptions on SWH and integrated soil fertility management technologies on sorghum and cowpea production in central Kenya

1. General information
   Farmer's date of birth (Age) ________________ Gender_____________
   Farm size_______________
   Farmer group/Organization: ______________________________
   Location____
   Division____
   District____
2. Level of education
   (i) None ☐
   (ii) Primary ☐
   (iii) Secondary ☐
   (iv) Post-secondary ☐

3. Which SWH methods do you apply on your farm?
   a) Tied ridging
   b) Contour furrow
   c) Conventional tillage/farmers practice
   d) None
   e) Others specify___________________________________
4. Among the three demonstrated SWH techniques which one do you consider most suitable for your farm? ____________________________________
   Reasons:
   a) ____
   b) ____
   c) ____

5. (i) Do you grow any of the following crops on your farm?
   a) Sorghum Yes ☐ No ☐
   b) Cowpea Yes ☐ No ☐
   c) Both Yes ☐ No ☐

(ii) If you grow them, what method for planting do you use?

   a) Monocropping sorghum

b) Monocropping cowpea
c) Intercropping of sorghum and cowpea
d) Other specify ____

(ii) If intercropped what method do you use?

a) Same row

b) Different rows

c) Other specify ____

5. (i) Which of the following input(s) do you apply to improve soil fertility on your farm?

a) Manure

b) Fertilizer

c) Both

d) None

Others specify____

(ii) Give reasons for the preferred input(s)

____

6. According to your own observations, score the following plots in terms of performance on a scale of poor, fair and good.

Plot no.	Score			Plot no.	Score			Plot no.	Score		
	Poor	Fair	Good		Poor	Fair	Good		Poor	Fair	Good
1				48				95			
2				49				96			
3				50				97			
4				51				98			
5				52				99			
6				53				100			
7				54				101			
8				55				102			
9				56				103			
10				57				104			
11				58				105			
12				59				106			
13				60				107			
14				61				108			
15				62							
16				63							

17				64							
18				65							
19				66							
20				67							
21				68							
22				69							
23				70							
24				71							
25				72							
26				73							
27				74							
28				75							
29				76							
30				77							
31				78							
32				79							
33				80							
34				81							
35				82							
36				83							
37				84							
38				85							
39				86							
40				87							
41				88							
42				89							
43				90							
44				91							
45				92							
46				93							
47				94							

Appendix IV: Publications

Publications in Refereed Journals:

Peterson N.M. Njeru, Jayne Mugwe, Monicah Mucheru-Muna and Stephen Kimani. 2024. The effects of Integrated Soil fertility Management and Cropping Systems on Soil Water Content on Sorghum and Cowpea production in central highlands of Kenya. Tropical and Subtropical Agroecosystems 27 (2024): Art. No. 133. http://doi.org/10.56369/tsaes.5326

Njeru, P.N.M., Maina, I.,Lekasi, J.K., Kimani, S.K., Esilaba, A.O., Mugwe, J. and Mucheru-Muna, M. 2016. 'Climate smart agriculture adaptation strategies for rain-fed agriculture in drought-prone areas of Central Kenya', *Int. J. Agricultural Resources, Governance and Ecology*, Vol. 12, No. 2, pp.113–124. https://doi.org/10.1504/IJARGE.2016.076928.

Njeru P. N. M., Mugwe J.Maina I., Mucheru-Muna M., Mugendi D., Lekasi, J. K., Kimani S. K., Miriti J., Esilaba A. O. and Muriithi F. 2014. Integrating scientific and farmers' perception towards evaluation of rain-fed agricultural technologies for sorghum and cowpea productivity in Central Kenya. *J. Soil Sci. Environ. Manage*. 4(7): 123-131. https://DOI:10.5897/JSSEM2013.0378.

P.N.M. Njeru , J. Mugwe, M. Mucheru-Muna, I. Maina, D.M. Mwangi, S. Amboga, M. Miruka, J.K. Lekasi, S.K. Kimani, J. Miriti, J. Gitari, M. Mahasi, K. Mutea and F. Muriithi. 2013. Integrating scientific and farmers' evaluation of water harvesting and soil fertility technologies on sorghum productivity in Eastern Kenya. *E. Afr. agric. For. J*. 78(3), 143-150. https://www.researchgate.net/publication/262680245.

Publications in Book chapters:

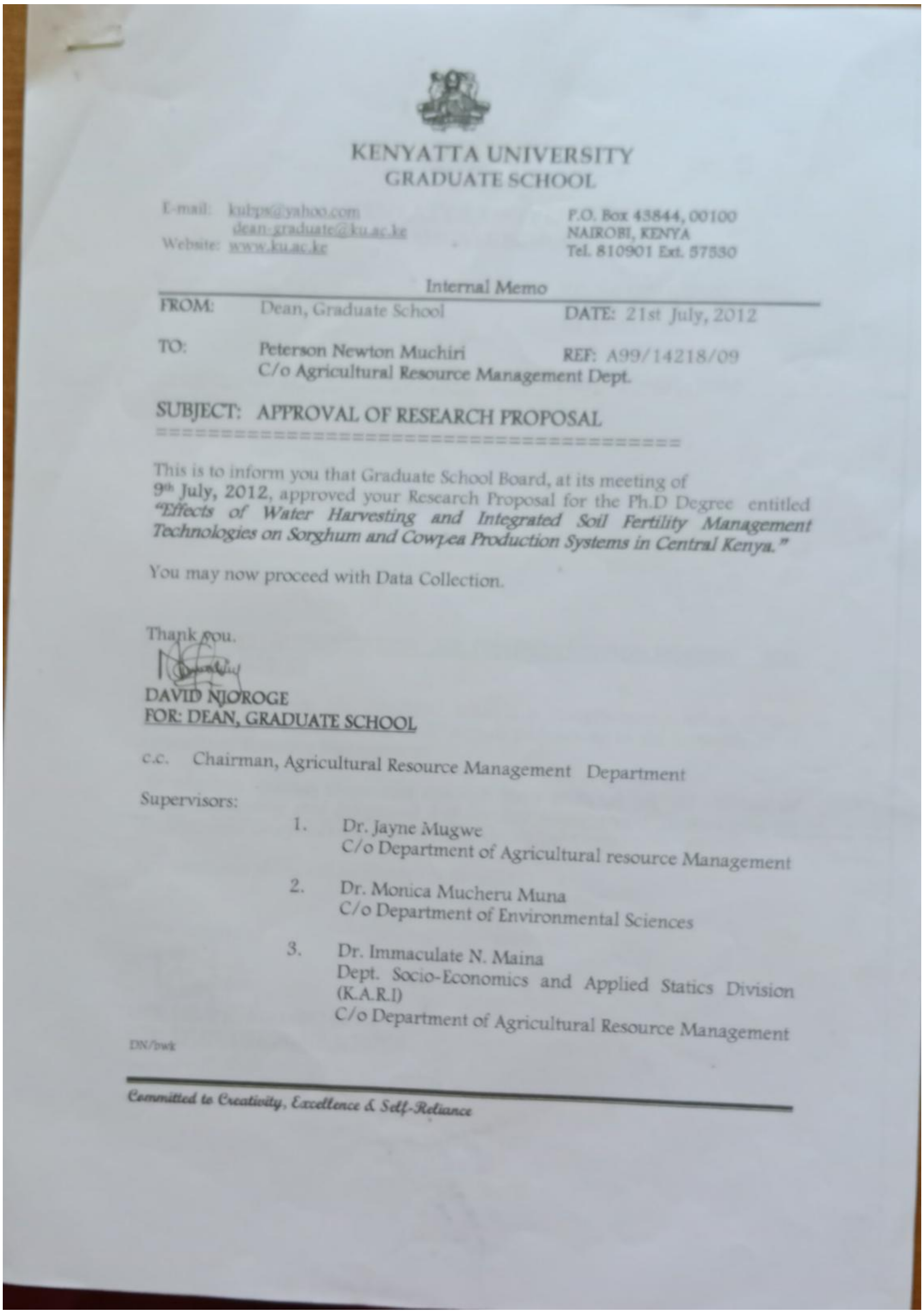
Peterson N. M. Njeru1 , Jayne Mugwe2 , Monicah Mucheru-Muna2 , Immaculate Maina3 , Stephen K. Kimani1 and David K. Lelgut1 . 2019. Drought-Tolerant Crops in Kirinyaga County, Kenya: Climate-Smart Agriculture Adaptation Strategies. Handbook of Climate Change Resilience, © Springer Nature Switzerland AG 2018. 10.1007/978-3-319-71025-9_80-1. https://doi:10.1007/978-3-319-71025-9_80-1.

Njeru P. N. M, Mugwe J, Maina I, Mucheru-muna M, Mugendi D, Lekasi JK and Kimani SK. 2015. Adapting rain-fed agriculture to climate change variability: An overview of sorghum (Sorghum bicolor (L). and cowpea production in agro-pastoral areas of eastern Kenya. United Nations Development Programme-Kenya. Nairobi. *ISBN 978 9966 1805 5 1.*

Njeru P. N. M, Mugwe J, Maina I, Mucheru-Muna M, Mugendi D, Lekasi, J.K, Kimani S. K, Miriti J, Oeba V. O, Esilaba A.O, Mutuma E, Rao K.P.C and Muriithi F. 2014. Integrating Farmers and Scientific Methods for Evaluating Climate Change Adaptation Options in Embu County. springer verlag publisher. International

Publishing, Switzerland. *ISSN 16110-2010*. https://doi.org/10.1007/978-3-319-93336-8.

.APPENDIX V: RESEARCH APPROVAL



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Internal Memo

FROM: Dean, Graduate School   DATE: 21st July, 2012

TO: Peterson Newton Muchiri   REF: A99/14218/09
C/o Agricultural Resource Management Dept.

SUBJECT: APPROVAL OF RESEARCH PROPOSAL

This is to inform you that Graduate School Board, at its meeting of 9th July, 2012, approved your Research Proposal for the Ph.D Degree entitled *"Effects of Water Harvesting and Integrated Soil Fertility Management Technologies on Sorghum and Cowpea Production Systems in Central Kenya."*

You may now proceed with Data Collection.

Thank you.

DAVID NJOROGE
FOR: DEAN, GRADUATE SCHOOL

c.c. Chairman, Agricultural Resource Management Department

Supervisors:

1. Dr. Jayne Mugwe
   C/o Department of Agricultural resource Management
2. Dr. Monica Mucheru Muna
   C/o Department of Environmental Sciences
3. Dr. Immaculate N. Maina
   Dept. Socio-Economics and Applied Statics Division (K.A.R.I)
   C/o Department of Agricultural Resource Management

DN/bwk

Committed to Creativity, Excellence & Self-Reliance

Appendix VI: Research Authorization

KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 8710901 Ext. 57530

DATE: 21st July, 2012

Our Ref: A99/14218/09
Your Ref:

The Permanent Secretary,
Ministry of Higher Education, Science & Technology,
P.O. Box 30040,
NAIROBI

Dear Sir/Madam,

RE: RESEARCH AUTHORIZATION MR. PETERSON NEWTON MUCHIRI – REG. NO. A99/14218/09

I write to introduce **Mr. Muchiri** who is a Postgraduate Student of this University. He is registered for PH.D degree programme in the **Department of Agricultural Resource Management.**

Mr. Muchiri intends to conduct research for a proposal entitled, "***Effects of Water Harvesting and Integrated Soil Fertility Management Technologies on Sorghum and Cowpea Production Systems in Central Kenya.***"

Any assistance given will be highly appreciated.

Yours faithfully,

for:

MRS. LUCY N. MBAABU
FOR: DEAN, GRADUATE SCHOOL

LNM/bwk

Committed to Creativity, Excellence & Self-Reliance

Appendix VII: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 559613

Date of Issue: 06/March/2024

RESEARCH LICENSE

This is to Certify that Mr.. Peterson Newton Muchiri Njeru of Kenyatta University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Embu, Kirinyaga on the topic: Effect of water harvesting and integrated soil fertility management technologies on sorghum and cowpea production systems in central Kenya for the period ending : 06/March/2025.

License No: NACOSTI/P/24/33794

559613

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

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Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix VIII: Work Plan

	Activity/sub-activity	Duration Year 2022
		Status
1	Proposal development and defense	Done
2	Proposal submission and approval	Done
3	Identification of field sites	Done
4	Soil sampling for baseline characterization	Done
5	Planting season 1 and 3 Short rains	Done
6	Measurement of cost benefit data	Done
7	Sorghum grain yield and heights measurements as affected by water harvesting and ISFM technologies for 3 season in 2 Counties	Done
8	Monitoring of inputs and outputs on sorghum and cowpea production	Done
9	Farmers evaluation on crop performance (Field days held)	Done
10	Planting season 2 long rains	Done
11	Soil water retention measurement for selected water harvesting technologies	Done
12	Soil sampling at the end of the experiment	Done
13	Scientific papers writing and publishing	7 Papers already published in refereed journals, book chapters and International conference proceedings.
14	Data compilation, analyses and writing of 1st thesis draft	Done
15	Submission of 1st thesis draft	By 15th January 2022
16	Presentation of 1st progress report	By 30th June 2022
14	Presentation of 2nd progress report	By 29th July 2022
15	Presentation of 3rd Progress report	By 28th October 2022
16	Submission of final thesis for examination	By May 2024

17	Thesis defense pending graduation	By June 2024