INTEGRATING IN-SITU RAIN WATER HARVESTING TECHNOLOGIES AND ORGANIC MANURE FOR IMPROVED SOIL MOISTURE AND MAIZE PERFORMANCE IN SEMI-ARID OF MOROGORO, TANZANIA

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DECLARATION

I Julieth Joseph Balilemwa declare that this thesis is my original work and has not presented for a degree in any other University or for any other award.

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DEDICATION

To my mother Flora Masasi and late father Joseph Balilemwa, for recognition of the importance of education in life and in ensuring that I am provided with one.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
ANOVA	Analysis of Variance
ARM	Agriculture Resource Management
CV	Coefficient of Variation
DMRT	Duncan’s Multiple Range Test
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistical
FOM	Furrow without Manure
FWM	Furrow with Manure
iAGRI	Innovative Agricultural Research Initiative
IFRC	International Foundation of Red Cross
LSD	Least Square Difference
MOM	Mulching without Manure
MWM	Mulching with Manure
RCBD	Randomized Complete Block Design
RUFORUM	Region University for Capacity Building in Agriculture
RWHT	Rainwater Harvesting Technologies
SAS	Statistical Analysis Software
SPSS	Statistical Package for Social Science
SSA	Sub-Saharan Africa
TOM	Traditional without Manure
TWM	Traditional With Manure
USAID	United State Agency International Development
WHO	World Health Organization

ABSTRACT

Tanzania experiences water scarcity caused by unreliable rainfall and prolonged droughts. The objective of this study was to determine in-situ rainwater-harvesting technologies used by smallholder farmers to cope with water scarcity and assess the effect of integrated in-situ rainwater harvesting technologies with organic manure on soil moisture content and maize performance in the semi-arid part of Morogoro region in Tanzania. This study included both experimental and survey method. A household survey was conducted in Gairo district while the experiment was carried out at Sokoine University Agricultural farm. The treatments were traditional cultivation without manure (TOM), mulching without manure (MOW), furrows without manure (FOM), Zai pits without manure (ZOM), Zai-pits with manure (ZWM), mulching with manure (MWM), furrows with manure (FWM) and traditional cultivation with manure (TWM) which laid out in a randomized complete block design and replicated thrice. The experimental data were subjected to the analysis of variance using Statistical Analysis Software version 9.4. Survey data were analyzed using Statistical Package for Social Sciences version 16. The survey results showed that smallholder farmers in Gairo district had no knowledge on Rainwater Harvesting techniques for overcoming water scarcity, where, 95.8% of Ibuti and 89.6% of Tabuhoteli farmers planted drought-tolerant crops as a coping strategy during water scarcity periods. This was attributed to lack of in-situ RWHTs knowledge expressed by 97.9% of Ibuti and 83.3% of Tabuhoteli farmers. Experimental results showed that there were significant differences ($p<0.05$) in soil moisture retention among treatments at 0 –20 cm and 20–40 cm of soil depths, which ranged from 9.72%-16.16% and 13.52%-17.67%, respectively. The highest soil moisture content was observed in the mulching treatments without manure 16.16% at 0–20 cm and 17.67% at 20–40 cm compared with the control that had 10.44% at 0–20 cm and 13.52% at 20–40 cm. Maize and stover yields differed significantly among the treatments.. Conventional traditional practice had the lowest maize grain weight and biomass weight (3.2 t ha^{-1} and 3.4 t ha^{-1}) compared to other treatments. The integration of mulching and organic manure resulted in the highest maize grain weight and biomass weight (5.1 t ha^{-1} and 6.2 t ha^{-1}) compared with the traditional practice. This implies that there is a need for promoting a combination of in-situ rainwater harvesting technologies and manure applications especially the use of mulching technology with manure.

CHAPTER ONE

INTRODUCTION

1.1 Background

Approximately, one billion people of the world's population are starving (FAO, 2010), with more than 50% residing in developing nations of the sub-Saharan region (FAO, 2011). It expected that the sub-Saharan region might host 40% of the arena's poor populace (Chen and Ravallion, 2007). Poor households often live in rural areas in order to sustain their livelihoods. They are engaging in farming as their main economic activity (IFAD, 2011), but they have limited access to natural resources such as water (Enfors and Gordon, 2008). Farmers are therefore forced to cultivate under poor quality soils while being confronted by challenges of inadequate conservation technologies as well as unreliable rainfall (Arslan et al., 2017). For decades, the farmers have relied on farming systems that exhibit low efficiency while depending on inputs and technologies that worsen productivity (Arslan et al., 2017). Meanwhile, the revelation of the depleting productivity through poor soil moisture requires adequate investments in agriculture.

Investment in agriculture could be the farmers' pathway out of low productivity in sub-Saharan Africa (Pretty et al., 2011). This estimation illustrates the effectiveness of agricultural investment in improving productivity (Christiaensen et al., 2011). However, due to the ongoing climatic conditions, water shortage is one of the threats to agricultural productivity (Asfaw and Neka, 2017; Almazroui et al 2020). Low agricultural productivity is common in areas where water resource is limited (Tumbo, 2003; Kundzewicz, et al., 2009). Unpredictable occurrences of droughts make water resource an uncertain factor (IPCC, 2012). Unsustainable agricultural water management is deleterious to the soil, thus, it is imperative to note that sustainable water resource management is vital in attaining sustainable agricultural strengthening. Previous studies have earmarked rainwater harvesting as one of the key components of sustainable water resources management approaches that could increase agricultural productivity and protect the environment (Liniger et al., 2011).

Tanzania is a country that mainly depends on rain-fed agriculture, thus its farming systems are likely to be vulnerable to climate variability, especially in the semi-arid and arid areas of central and northern regions (FAOSTAT, 2005). Due to unpredictable trend of rainfall amounts and timing, smallholder farmers’ fields are afflicted by low soil moisture content material and maize crop yield (Nellemann et al., 2009). It has reported that conservation technologies can increase soil moisture and agricultural productivity in addition to meals security in arid and semi-arid areas such as Kilimanjaro, Shinyanga and Dodoma regions (Arslan et al., 2017). Rainwater harvesting (RWH) technologies are one of the conservation technologies that boom the quantity of water stored in the soil inside the root sector and prevent internet runoff for a prolonged duration to permit infiltration to take location (Katrin and Boubacar, 2009). Moreover, soil water resulting from the harvested rainwater make nutrients available to plants for uptake (Achandi et al., 2018). Regardless of the previous research that has been done in Tanzania concerning rainwater harvesting techniques, still, there is low use of in-situ RWH techniques by means of smallholder farmers in the semi-arid part of Morogoro in Tanzania (Scheierling et al., 2013). However, the combination of the in-situ RWHTs and organic manure results in both high moisture storage and yield. A study conducted in Zimbabwe by (Kugedera and Kokerai, 2019) showed that the combination of pits, ridge and cattle manure resulted in high grain yield where pits produced 4.40 t/ha and ridges produced 3.84 t/ha. Mulching stored soil moisture and increased yield by reduced soil evaporation between 30–50% during unreliable rainfall (Mupangwa et al., 2019). Therefore, there is a need to assess the in-situ RWHTs implemented by farmers and integrating in-situ rainwater harvesting technologies and organic manure for improved soil moisture and maize performance in the semi-arid of Morogoro, Tanzania.

1.2 Problem Statement

Poor soil moisture retention and low crop productivity is the principal challenges facing smallholder farmers in semi-arid areas in East Africa. Tanzania is among the sub-Saharan countries that are experiencing the problems because smallholder farmers practise rain-fed agriculture. Low and unreliable rainfall distribution coupled with temperature increases is a number of weather-associated demanding situations confronting small-scale farmers in the semi-arid part of Morogoro region in Tanzania (Magehema et al., 2014). This has contributed to low food production in the region in recent decades especially in Gairo District (Sangeda et al., 2013). In the District, farmers are practising traditional farming technologies that are lowering soil moisture storage as well as productivity. Furthermore, the use of in-situ RWH technologies in the district is so limited. Because of decreased crops production, more than 20% of the families are engaging in the sale of their treasured assets to buy food and approximately 40% of those without property seek help from their neighbours for survival (*ibid*). Therefore, this work looks at the usefulness of mulching, furrows, zai pits and organic manure as technologies that would adapt by farmers in dealing with water scarcity and hence promote crop production.

1.3 Justification of the Study

Smallholder farmers in East Africa practice traditional or indigenous practices in agricultural activities. However, this triggers low moisture storage in the soil as well as low productivity (Waithaka, 2013). Researchers have shown that the use of water and soil conservation technologies have impacts on both soil moisture content and crop yield compared to traditional technologies (Mlegera et al., 2015). Zai-pit, furrow and mulching are among conservation technologies where the practice of these technologies increases moisture storage. However, integrating these technologies and organic manure can improve yield in the semi-arid part of Morogoro, Tanzania (Tumbo, 2003). Smallholder farmers in Tanzania are trying to use different indigenous technologies in order to improve soil moisture content (Mvena and Kilima, 2009). However, the effectiveness of such technologies in controlling and conserving soil moisture has not been addressed (Mlengera et al., 2016). This work, therefore, aimed at examining the impact of integrating in-situ RWH technologies and natural manure on soil moisture and maize yield in the semi-arid part of Tanzania.

1.4 Objectives

1.4.1 General Objective

To determine in-situ rainwater harvesting technologies used by smallholder farmers to cope with water scarcity and assessment of integrated in-situ rainwater harvesting technologies with organic manure on soil moisture content and maize productivity in the semi-arid part of Morogoro region, Tanzania.

1.4.2 Specific Objectives

i. To assess the rainwater harvesting technologies adopted by smallholder farmers for water scarcity in semi-arid parts of Morogoro region.

ii. To assess the effect of integrating in-situ rainwater harvesting technologies and organic manure on soil moisture in semi-arid areas of Morogoro.

iii. To assess the effect of integrating in-situ rainwater harvesting technologies and organic manure on maize performance in semi-arid parts of Morogoro.

1.5 Hypotheses

i. **H1**; the adoption of rainwater harvesting technologies significantly cope with water scarcity

H0; the adoption of rainwater harvesting technologies not significantly cope with water scarcity

ii. **H1**; the integration of in-situ rainwater harvesting technologies with organic manure significantly improves soil moisture content.

H0; the integrating of in-situ rainwater harvesting technologies with organic manure does not significantly improve soil moisture content

iii. **H1**; Integrating in-situ rainwater harvesting technologies with organic manure significantly increases maize performance.

H0; Integrating in-situ rainwater harvesting technologies with organic manure does not significantly increase maize performance.

1.6 Significance of the study

The outcomes of this study will help smallholder farmers to conserve soil moisture storage that results to increase crop production. Moreover, they will be useful for encouraging policymakers and the private sector to invest in the existing in-situ rainwater harvesting techniques through supporting smallholder farmers to use the technologies. In addition to that, results from this study will help to develop effective and reliable strategies for reducing water scarcity and improving soil moisture retention.

1.7 Conceptual Framework

The conceptual framework in Fig. 1 indicates the connection between the established variables, such as increased maize productivity, increased soil moisture content and the independent variables, which include in-situ RHTs and organic manure. The usage of rainwater harvesting techniques is conceptualized to reduce the water scarcity challenge through increased water availability and infiltration rate, thus, increasing soil moisture content. The combination of in-situ RWH technologies and organic manure is expected to improve both soil nutrients and their transportation, hence result in an increased crop yield.

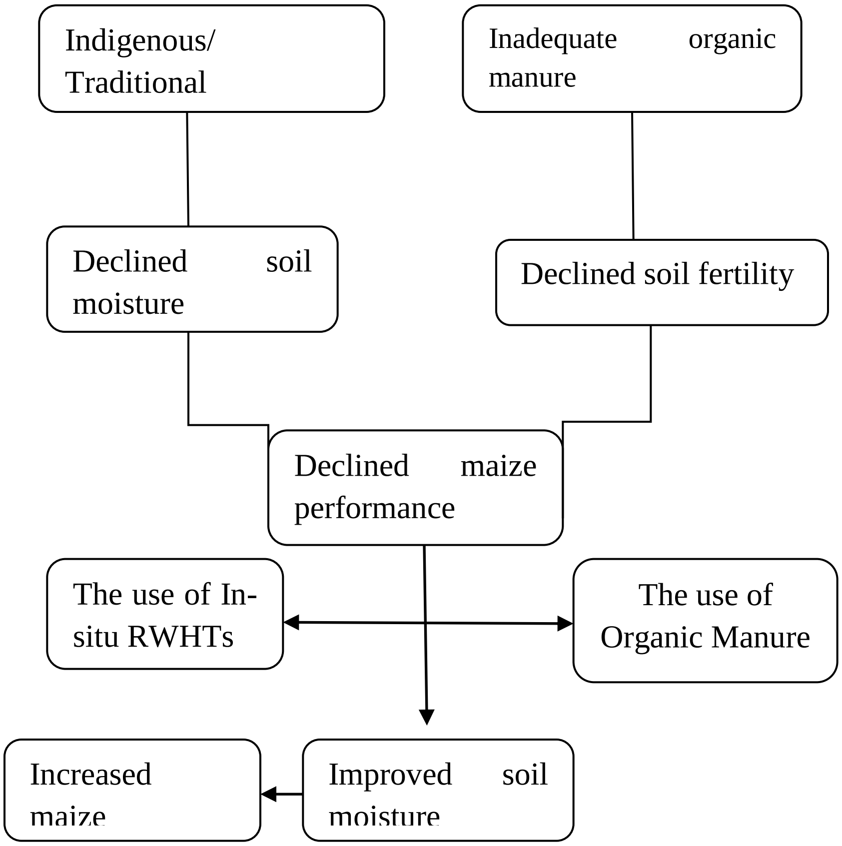

Figure 1: Conceptual framework

CHAPTER TWO

LITERATURE REVIEW

2.1 General overview

Water scarcity has a negative impact on agriculture in Africa (FAO, 2011) with the majority of East African regions facing the challenge of unpredictable and highly variable rainfall patterns (Khaka et al., 2006). Smallholder farmers in Tanzania use methods of water management that are becoming more effective through the progressive development of adaptive capacities (Tumbo, 2003). One such method is rainwater harvesting technologies (Mvena and Kilima, 2009). Rainwater-harvesting technologies are divided into two categories namely, external RWH and in-situ RWH. External water harvesting is the technique of gathering, conveying and storing harvested rainwater that may assist to mitigate the impact of climate alternate specifically rainfall variability (Gowing 2003; Magehema et al., 2014). In-situ RWH technologies are also called water conservation technologies because they are set up in the fields (Mlegera et al., 2016). Recent focus has directed towards the suitability of in-situ technologies based on the results of on-station experiments. Technologies could cushion farmers against water scarcity and reduce the effects of climate change.

2.2: The use of rainwater harvesting technologies by smallholder farmers

The numbers of smallholder farmers who are using RWH systems are still very low due to different factors (Oloro et al., 2007). Odhiambo et al., 2021 reported that in order to encourage smallholder farmers to RWH technologies, they must have a chance to understand their needs on RWHTs. This is because farmers are using irrigation to overcome water scarcity although, for smallholder farmers, it is an expensive technology (*ibid*). However, researchers have a role to play by helping farmers to incorporate their local knowledge in building rainwater technologies (Mugendi et al., 2007). Therefore, there is a need for training communities in order to ensure that RHW technologies remain sustainable (AfDB, 2006)**.**

2.3 Water scarcity and coping strategies

The agricultural activity in Tanzania is rain-fed and incredibly liable to climatic fluctuations (Kayombo, 2014). A huge part of the country is semi-arid and thus susceptible to both water scarcity and unreliable rainfall that are limiting factors to agricultural production (Mmbanga and Lyamchai, 2001 and World Bank, 2007). This case has been worse with the aid of the alteration in climate conditions especially rainfall pattern which affects soil moisture content (David et al., 2002). Poor soil moisture content affects crops and results in low productivity (Purcell et al., 2007). One of the worst-performing sectors in the economy has been agriculture productivity due to water scarcity

(World Bank 2007). Farmers in Tanzania have responded to these changes by engaging agricultural production using basic technologies thus, it projected that the Country will face water scarcity by 2025 (Water Council, 2000). Water scarcity can be addressed by using sustainable technology for agricultural production (David et al., 2002). Smallholders in semi-arid areas in Tanzania such as Kilimanjaro are using different methods for coping with water scarcity. Such methods include conservation technologies and irrigation in order to increase soil moisture content (Godsey, 2012), however other methods such as in-situ RWHTs are limited.

2.4 Rainwater harvesting technologies and agricultural production

Water is very important in the agricultural sector since crops need (Fabrizil et al., 2015). Lack of water for agricultural activities affects soil moisture content and reduced crop yield (Mlengera et al., 2016). Rainwater harvesting technology is one of several ways that could increase soil moisture content. The advantage of RWH is that it provides water, thus reducing soil moisture stress and risk of crop failure thereby enhancing food security (Oweis et al., 2001).

Although agriculture is in particular rain-fed in sub-Saharan Africa, it is characterized by rainfall variability and climate change leading to low agricultural production (Below et al., 2010). The capability of water harvesting for improved crop production acquired first-rate interest inside the Seventies due to good-sized droughts, water scarcity and unreliable rainfall in Africa, which left a trail of crop disasters (Gowing, 2003). Researchers have shown that yield and reliability of agricultural production increased with RWH technologies (Inocencio et al., 2002). The RWH technologies can increase crop production in arid and semi-arid locations particularly in areas receiving rainfall between 200 to 700 mm (Munyayo, 2014; Kayombo, 2014). Food and Agriculture Organization (FAO, 2007) studies indicate that increasing productivity determines the availability of water.

2.5 Effect of in-situ rainwater harvesting technologies on soil moisture and maize yield

Soil moisture is highly affected by lack of water in soil; this can be due to prolonged drought or unreliable rainfall (Magehema et al., 2014). There is an instantaneous courting between rainfall and declining soil moisture content material (Mwango et al., 2015). Soil conservation technologies reduce the problem of unreliable rainfall and enhance soil moisture (Mlegera et al., 2016). Conservation agriculture appears to be the generally accepted technology through farmers due to its capability to increase crop yield and (Mlegera et al., 2016). In-situ RWH is the simplest and affordable technology that practised under all land use systems (Munyayo, 2014). It has been reported that the use of in-situ RWH technologies could increase food security

(Malesu et al., 2007; Cai et al., 2015; Mowo, 2006). In-situ rainwater harvesting technology can assist in protecting rainwater, thus increasing infiltration, which results in increased soil moisture content (Fabrizil et al., 2015).

2.5.1 Effects of zai-pits on soil moisture storage and maize yield

The zai-pits technique is an approach that aims at conserving, improving and making water more available, thus increase soil moisture content and double the yield (Hobbs et al., 2008). They are conservation semi-circular pits, which enhance rainfall infiltration and reduce surface run-off (Malesu et al., 2007). These pits mostly used in areas that receive an annual rainfall of less than 500 mm. Farmers in West Africa use small planting pits with dimensions (Danjuma and Mohammed, 2015). This technology also practised in the semi-arid counties of Kenya such as Machakos (Malesu et al., 2007). However, the use of zai-pits did not show a significant increase in crop yield in regions with > 500 mm rainfall (Mmbaga and Lyamchai, 2001). However, some of the pits introduced in some semi-arid areas in Tanzania require high labour because they are huge.

2.5.2 Mulching for improving soil moisture storage and maize yield

Mulches are good at conserving soil moisture in any field because soil with mulches absorb heat and lose moisture slowly (Lukman and Rattan, 2007). In addition, they reduce environmental stresses increase soil nutrients and speed up infiltration rate (Findeling et al., 2003; Mwango et al., 2015). Fields with mulches may have soil evaporation between 0.4 and 0.5 mm d^{-1} while those without mulches are between 1 and 1.17 mm d^{-1}(Zhang et al, .2005). Appropriate mulching can reduce the need for irrigation since it helps in the improvement of soil structure and increased soil moisture storage (Jolivet et al., 2003; Lukman and Rattan, 2007). Mulching in a field improves soil compartment (Bajracharya et al., 2005 and Mwango et al., 2015). Mulches increase plant height, crops population and biomass (Mowo, 2006). Since they store soil water providing more soil moisture at all stages of crop development. The use of mulches can also increase the average grain yield (Uwah and Iwo, 2011; Wei et al., 2015; Cai et al., 2015). However, smallholder farmers in Tanzania do not practice the technology, especially in farming maize growing.

2.6 Consequences of organic manure on soil moisture and maize yield

Organic manure obtained from animal waste and plant that used as a natural fertilizer, (Kayombo, 2006). Organic manure improves soil properties by adding organic matter (Hue and Silva, 2000). However, it contains a large quantity of soil nutrients (Guzman et al 2006; Hobbs 2007). The soils in Tanzania have low organic manure hence there is a need to use organic manure for the improvement of soil properties and increase crop yield (Mlegera et al., 2016). Organic manure can increase maize biomass yield, plant population and crop production from 3.2 to 3.7 t ha^{-1} (Achieng et al., 2010). In addition, organic manure has effects on crop parameters since it can produce the tallest maize (3.0 m) plant compared to maize cultivated without using organic manure (1.9 m) (Gary et al., 2007). It indicated the impact of organic manure on the improvement of soil fertility such that it doubled the yield of watermelon (Aniekwe and Nwokwe, 2015). However, there is high availability of organic manure to smallholder farmers but the use of organic manure for maize farming still limited.

2.7 Effects of soil moisture on maize performance

Plant height at maturity is an important component that helps determine the growth attained during the growing period of the crops. Soil moisture has a positive effect on plant growth because it transfers soil nutrients from the soil to the plants hence ensures plant health (Mowo, 2006). Previous research indicated that crops grown in soils with high moisture content are taller compare to soils with low moisture content (Uwah and Iwo, 2011). The study conducted in Tanzania showed that enough moisture content in soil results in high grain yield (Mwango et al., 2015; Cai et al., 2015). These support practical findings that conservation agriculture technologies can manage to store moisture content above 17% compared to ordinary farming (Mlengera et al., 2016). Therefore, the availability of soil moisture reflects the growth rate of the crops (Gicheru et al., 2004; Karuma et al., 2014). Crops planted under in-situ moisture conservation technologies can produce a high yield compared to conventional cultivation (Malligawad, 2010). In-situ moisture conservation technologies produced 80–100 % biomass yield and 70–350 % grain yield of maize (Muthamilselvan et al., 2006).

2.7: Furrow for improving moisture storage and maize performance.

Planting furrow is one of the in-situ RWHTs that increases soil moisture through harvesting rainwater and reduce runoff. Planting Furrows are like pits but the difference is that furrows are shallow in depth but wider. The practice is that farmers make furrows with tied ridges and planting crops on the ridge, not in the furrows (Nyakudya and Stroosnijder, 2013). However, these tied ridges are constructed to reduce soil erosion while furrow is for soil moisture storage (Gichangi *et al.,* 2012). It has reported that furrow with tied ridges increases productivity in semi-arid areas (Mutekwa, Kusangaya and Chikanda, 2006). However, some types of soil such as sandy soil had shown poor soil moisture storage (Kugedera and Kokerai, 2019).

CHAPTER THREE

METHODOLOGY

3.1 Study Area

3.1.1 Gairo District

Gairo is one of the districts of Morogoro region in Tanzania at a geographical location of 36^o 45' E and 6^o 30' S and an altitude of about 1000 m above sea level (Figure 2). Gairo has an average rainfall of 499 mm per year. The main crops include maize, cassava, sweet potatoes, cotton, lablab, soya beans and pigeon peas. The population of Gairo District is estimated at 193,011 with an average household size of 5.2 (URT, 2012).

Table 1: Soil characteristics and temperature of the study area (Mugasha et al., 2000)

Soil in the area classified	Haplic Lixisols
Soil texture	Sandy clay loam
Soil pH at 50 cm depth	6.1-6.2
Soil fertility	Low inherent fertility
Available phosphorus in the soil	0.18-3.38 ug/g
Natural vegetation	Shrubs, Miombo trees
Available nitrogen in the soil	0.11-0.16%
Temperature	21-30^o C

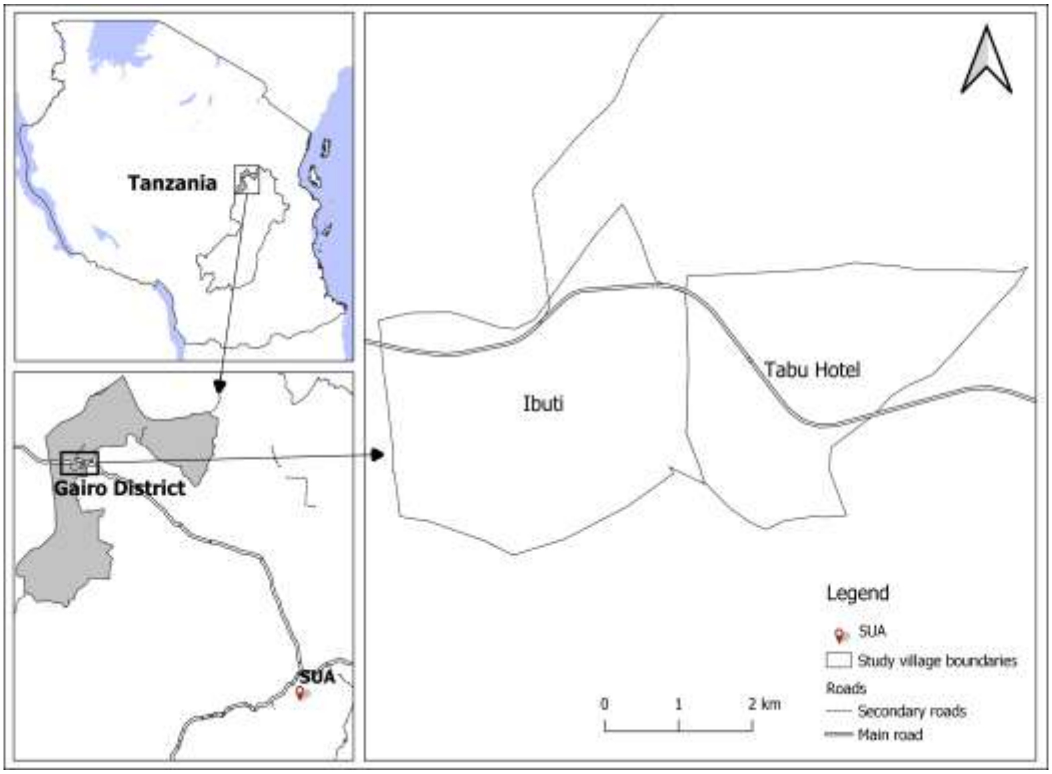

Figure 2: Map of Tanzania showing Morogoro region with Gairo District

3.1.2: Research Design

This study included both a survey design and an experiment (3.1.5). The survey was conducted in two villages in Gairo district. Both quantitative and qualitative data were collected from individual interviews at Tabuhoteli and Ibuti villages by using questioners. Two focus group discussions and three key in-depth informants were interviews for more information by using a checklist.

3.1.3: Population and sampling method

Sample sizes of 96 respondents were selected from the households using simple random sampling. The sampling frames were households.

$$\text{Sample size, n} = \text{N} * \frac{\frac{Z^2 * p * (1-p)}{e^2}}{[N - 1 + \frac{Z^2 * p * (1-p)}{e^2}]}$$

Table 2: Sample size formula

Specific	Significance
Population (N)	193, 011
(95% confidence level) (Z)	1.96
Margin of error (e)	0.005
a=Sample proportional uncertain (p)	0.5
B= Sample proportional	0.05
Sample (n)	96

3.1.4: Data collection

Data were collected by using questionnaires and interviews. An established questionnaire comprising of both open and closed-ended questions was used to collect data from the respondents (Appendix 1). The interview schedules involved visiting the sampled households with the assistance of a village elder.

3.1.5: Experimental design and management

The experiment was laid out in RCBD with eight treatments replicated thrice (28 experimental units plots). Weeds were controlled by weeding, while crop diseases were controlled by Karetep insecticide. Farmyard manure (9 t ha^{-1}) collected from SUA farm were applied in each plot

Table 3: Eight treatments in Experiment at SUA farm during rainy season

Treatments	**Inputs**	**Amount of manure**
TOM	Traditional conventional without manure	
TWM	Traditional conventional with manure	9 t ha^{-1}
MWM	Mulching with manure	9 t ha^{-1}
MOM	Mulching without manure	
FOM	Furrow without manure	
FWM	Furrow with manure	9 t ha^{-1}
ZOM	Zai-pit without manure	
ZWM	Zai-pit with manure	9 t ha^{-1}

The zai-pits were dug to break the crusted soil surface then the topsoil was returned to each of the pits. Zai pits measurements were 30 cm deep and 75 cm x

75 cm wide in which there were 8 plants/pit in 12 pits per plot. Maize seeds were planted in the middle of the zai- pits.

Plate 1: Zai pits without maize plant (A) and with maize plant (B).

The furrows were dug by using hoe to break the crusted soil surface then top soil returned to the furrows. The size of the furrows was 15 cm deep and 140 cm x 20 cm and that accommodated 16 maize plants. Maize seeds were planted in the middle of the furrows. There were six furrows per plot.

Plate 2: Planting furrows appearance without maize plant (A) and with maize plant (B)

Nine tonnes per hectare ($9\ t\ ha^{-1}$) of grass mulching was applied in a plot. Mulching was applied after crops emergence and first weeding, which means three weeks after planting. There were 10 holes/row and thus 80 holes/plot. In the net plot area, there were eight holes/row and two plants/hole which provided 96 plants. While the plot size was 6 m × 6 m and the net plot area was 4.5 m × 4.8 m. The spacing was 75 cm x 60 cm for plots with mulching and traditional cultivation, while 75 cm between rows for the plots with planting furrows and planting zai-pits. The maize seeds were planted in the middle of the furrows and pits. The maize crop was thinned to two plants per planting hole three weeks after emergence. When hand planting; fertilizer (DAP at a rate of 50 kg per acre) was also applied in the planting holes. All plots had similar plants population.

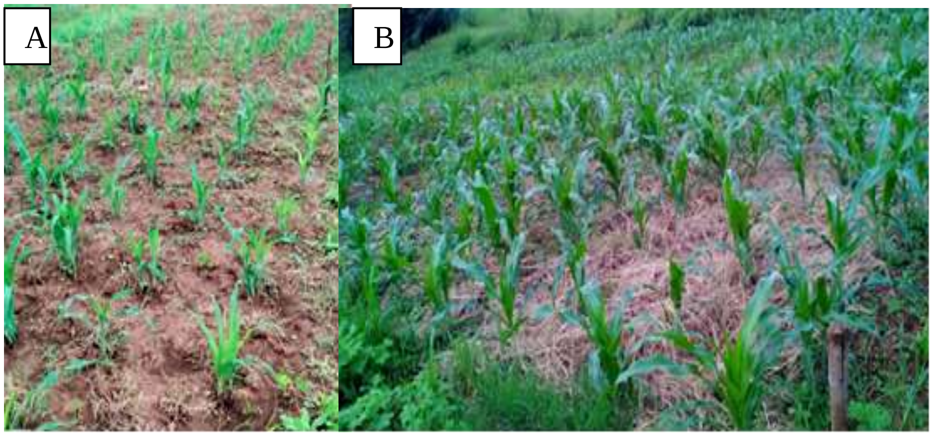

Plate 3: Plot appearance before (A) and after mulching (B)

3.2. Data collection

3.2.1 Determination of soil moisture in the field

Soil moisture content was determined using a moisture meter at a frequency of three times per week where the mean average values were calculated per week for each treatment. This was used to calculate the mean monthly soil moisture. A moisture meter was inserted in the soil at different depths (0-20 cm and 20-40 cm) in a zigzag design and moisture content readout. Soil moisture was taken at three spots per plot.

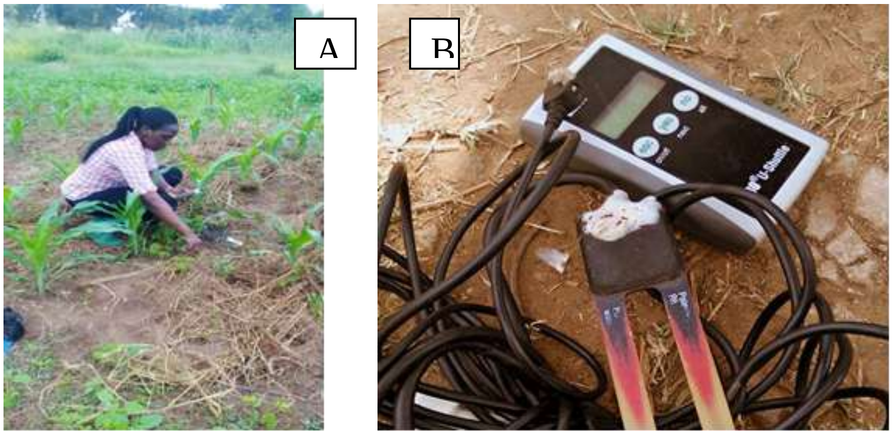

Plate 4: Moisture Meter (A) and Reading measurement using a Moisture Meter (B)

3.2.2 Measurement of crop development

Plant height was measured at different stages of crop development. The stages were germination stage, vegetative stage, flowering stage and fruiting stage from a point on the stem where roots start growing to the base of the highest fully expanded leaf using a tape measure. Maize was harvested from a net plot measuring 4.8 m × 4.5 m. The net plots consisted of eight middle rows in each plot, while the net plots of zai-pits and furrows comprised all plants that were within the furrow and pits measured in 4.8 m × 4.5 m. The grains were separated from the cobs by hand shelling. Grain moisture content was measured using a grain moisture meter at 13% in the post-harvesting laboratory at the Sokoine University of Agriculture (SUA). Grains were sun-dried to lower moisture contents. For reporting purposes, grains were corrected for moisture to a standard moisture content of 12.5%. Random samples of ten ears were selected from each plot and ear mass, the number of grains per ear and weight were determined by using a formula.

3.2.3 Rainfall measurement

Daily rainfall data was obtained from the Tanzania Meteorological Agency weather station at the Sokoine University of Agriculture (SUA), located 2 km from the experimental field.

During the short rainy season 2015 (October to December) there were a number of prolonged dry spells. One of the prolonged dry spells subsisted for 16 days from 27 November to 14 December 2015 (Figure 3). During the long rainy season in 2016, there was good rainfall occurrence in April followed by a number of prolonged dry spells from 6 May to 19 June 2016 (Figure 3).

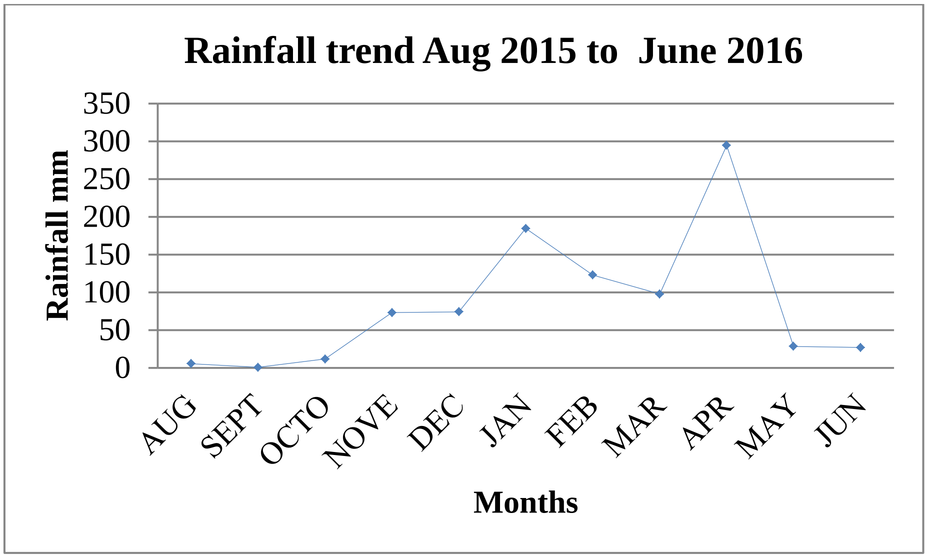

Figure 3: Daily rainfall data from August to December 2015 and from January to June 2016

3.3: Data analysis

Survey data were subjected to Chi-square and cross-tabulation analysis using SPSS version 16. Maize grain yield, biomass and soil moisture data were subjected to analysis of variance (ANOVA) using SAS software version 9.4. Treatment means separation was done using New Duncan Multiple Range Test (NDMRT) at $p < 0.05$.

Linear model for a RCBD design according to Searle and Gruber 2016given as:

$Yi\mathrm{j} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$ …………………………………………………..

Where;

Y_{ijk}= Response,

μ = Overall mean,

(τ_i and β_j ,) represent the effect of treatments and blocks respectively and

ε_{ij}= is the random error.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Characteristics of the respondents

Results indicate that 66.7% of respondents from Ibuti and 89.6% of respondents from Tabuhotel villages were female (Table 4). From which those who had attained primary education at Ibuti were 91.7% whereas at Tabuhotel were 97.9%.

In the study area, the dominance of female farmers was attributed to socio-cultural orientation. Women are generally resource-poor and experience gender-based biases towards access to resources. According to the cultures of most tribes in Gairo, women are expected to remain at home attending to their children and house chores. Additionally, one of their duties is to provide food to their families hence they are engaged in farming activities as a side hustle.

Table 4: Household characteristics of respondents in the study area

Social Demographic Characteristics	**Categories**	**Ibuti**	**Tabuhotel**	**x^2 Value**
Sex	Male	16 (33.3)	5 (10.4)	0.001*
	Female	32 (66.7)	43 (89.6)	
	Total	48	48	
Education level	No education	3(6.3)	1 (2.1)	0.350^{ns}
	Primary	44 (91.7)	43 (89.6)	
	Secondary	1 (2.1)	4(8.3)	
	Total	48	48	
Family Position	Father	15 (31.3)	5(10.4)	0.011^{ns}
	Mother	31 (64.6)	43 (89.6)	
	Child	2 (4.2)	0 (0)	
	Total	48	48	
Occupation	Farmer	46 (95.8)	48 (100)	0.360^{ns}
	Non-Farmer	2 (2.1)	0 (0)	
	Total	48	48	

Values in parentheses are percentages *= statistical significant at $p<0.01$and ^{ns}=not significant

The majority of the farmers from both villages had attained primary school education as indicated in table 4, which is a result of the implementation of education programmes in Gairo district and all over the country. Galabawa (2000) reported that most villagers attend primary schools than secondary schools. Respondents with informal education and primary education were able to explain their local knowledge about farming technologies, which is under application. The findings support observation by Liberio (2012) who reported that smallholder farmers in Tanzania who had attained informal and primary education were using a tradition farming system. One of the local technologies used at Gairo is ridges for growing potatoes that help them to reduce soil erosion.

The majority of households in Gairo District are involved in farming because agriculture is their main source of livelihood. They attributed this to lack of secondary education because their assumptions were that with secondary education one exposed to more job opportunities. Other researchers agreed that agriculture is the most financially beneficial activity in the District (Belowa, et al. 2010; Mutabazi et al., 2014). World Bank, 2007 reported that it is the responsibility of women to sell the produce as well as taking care of other domestic responsibilities such as buying food and clothes.

The following is the excerpt from the focus group discussions:

> *"...In our villages, mothers are responsible for rising of the children. She must make sure that children have clothes, education, food and all other basic needs"*

4.2 Agriculture as a source of income to smallholder farmers

A large proportion of farmers from Ibuti (66.7%) and Tabuhoteli (60.4%) villages indicated that farm produce contribution to total household income is between 31-60%. Moreover, 93.8% of farmers from Ibuti and 83.3% from Tabuhoteli reported that the total land size cultivated for crop production is within 1 acre to 5 acres. The significant association between land sizes cultivated within the district implied that farmers in Tabuholeti village were more likely to put more land under cultivation than Ibuti. The major crops cultivated in both villages did not show significant association ($p = 0.474$). This implied that both villages had similar major crops (Table 5).

Table 5: Agriculture activities in the study area

Variables	Categories	Ibuti	Tabuhoteli	x^2 value
Farm produce contribution to household income	<30%	16 (33.3)	19 (39.6)	0.093^{ns}
	31-60%	32 (66.7)	29 (60.4)	
	61-90%	0 (0)	0 (0)	
	>90%	0 (0)	0 (0)	
	Total	48	48	
Total land cultivated for crop production (acres)	0-5	45 (93.8)	40 (83.3)	0.099^{ns}
	6-10	3 (6.2)	8 (16.7)	
	Total	48	48	
Major crops cultivated	Maize	20 (41.7)	28 (58.3)	0.474^{ns}
	Potatoes	28 (58.3)	17 (35.4)	
	Beans	0 (0)	1 (2.1)	
	Sunflower	0 (0)	2 (4.2)	
	Total	48	48	

Values in parentheses are percentages *= statistical significant at $p<0.01$and ^{ns}=not significant

This study found that agriculture contributing more than any other activity in the district. However, Belowa et al., (2010) reported that due to poor agricultural productivity per capita income of Gairo District is less than 50%. These findings supporting by World Bank (2002) found out that more than 50% of people from Sub-Saharan Africa depend on agriculture for their income. The farmers from both villages cultivated potatoes in ridges while maize cultivated using traditional technology. Farmers have been using local knowledge to cultivate these crops because they have no alternative technology. Barakaitze et al., 2017 also observed this and reported that most farmers in Tanzania practice indigenous knowledge because of poverty. Moreover, crops cultivated in the area were maize and potatoes, the staple and commercial food crops. Yamane et al., 2018 conducted a study on food consumption in Tanzania found out that maize is a staple food as well as cash crop most parts of Morogoro region.

The following is an excerpt from one of the participants of the focus group:

> *"…Contribution of agriculture to our income is more than any other activity because for someone to become a farmer s/he does not need formal education. What one needed is to adopt new technologies that our agricultural extension officers do, which leads to an increase in production that translates to more money. For example technologies that we have adopted are the use of inorganic fertilizers such as UREA and NPK and hybrid maize seeds"*

4.3 Water scarcity coping strategies

All respondents (100%) from both villages indicated that they are practising rain-fed agriculture (Table 6). on the other hand, the majority of the farmers showed that water availability for agricultural activities was low (50% Ibuti and 60.4% Tabuhoteli). Scarcity of water and crop productivity at both villages did not show statistical significance (p=0.730). Moreover, the majority of the farmers from both villages indicated that the causes of water scarcity were climate change (81.3% Ibuti and 56.2% Tabuhoteli) followed by deforestation (18.7% Ibuti and 43.8 % Tabuhoteli). The respondents planted drought-tolerant crops as coping strategies during water scarcity periods, which were supported by 95.8% of respondents at Ibuti and 89.6% at Tabuhoteli. During data collection, it was indicated that where drought persisted, they could not continue with farming activities due to a lack of an alternative. This is a village where farmers had never practised irrigation.

Potential water sources such as rivers and lakes are not within the vicinity of the villages. From the results, it is observed that the majority of the farmers have been relying on rain-fed agriculture because of a lack of resources to support the installation of irrigation systems. Mdemu et al., 2017 support this finding, who reported that major challenges toward investment in irrigation are water supply and infrastructure. Moreover, Gowing, 2003 reported that in Sub-Saharan Africa, irrigation is not common especially in rural areas, so most of the farmers depend on green water to grow their crops. Farmers in the Gairo district have been relying on different approaches such as planting drought-tolerant crops as strategies toward water scarcity this actual result in poor productivity. Magehema et al., 2014 and Senkondo, 2004 also reported similar observation who indicated that production of maize is very low due to climate variabilities such as an increase in temperature and poor rainfall.

Table 6: Availability of water for agriculture and farmers' coping strategies against water scarcity in Gairo District

Variables	Categories	Ibuti	Tabuhoteli	x^2 Value
Scarcity of water and productivity	Satisfactory	4 (8.3)	5 (10.4)	0.730^{ns}
	Poor	9(18.8)	10 (20.8)	
	Very poor	35 (72.9)	33 (68.8)	
	Total	48	48	
Causes of water scarcity persistence	Climate change	39 (81.3)	27 (56.2)	0.008*
	Lack of source of water and Environmental destruction	9 (18.7)	21(43.8)	
	Total	48	48	
water scarcity Coping strategies	Irrigation	0 (0)	0 (0)	0.001*
	Drought	2 (4.2%)	5 (10.4)	
	crops Others	46 (95.8)	43 (89.6)	
	Total	48	48	
Water availability for agricultural activities	Highly	0 (0)	0 (0)	0.106^{ns}
	Adequate	4 (8.3)	0 (0)	
	Low	24 (50)	29 (60.4)	
	Very low	20 (41.7)	19 (36.6)	
	Total	48	48	
Source of water for agriculture activities	Rainfall	48 (100)	48 (100)	0.315^{ns}
	Rivers	0 (0)	0 (0)	
	Lake	0 (0)	0 (0)	
	Others	0 (0)	0 (0)	

Values in parentheses are percentages *= statistical significant at $p<0.01$and ^{ns}=not significant.

4.4: Barriers to invest in in-situ RWH techniques

Results showed that the majority of the farmers from Ibuti (97.7%) and Tabuhoteli (83.3%) had never attended any programme that would raise general awareness on in-situ rainwater harvesting technologies (Table 6). There was a significant association (p <0.05) between in-situ rainwater harvesting technologies and income, and poor support from the government. The majority of the respondents mentioned lack of information being the reason for not investing in in-situ RWH techniques while only a few respondents (33.3%) stated that low income limited their investment capacity on in-situ RWH technologies.

Results (Table 7) indicated that more than 60% of the smallholder farmers in Gairo district failed to invest in in-situ RWH techniques due to lack of knowledge on the technology while more than 35% indicated to be due to lack of capital. These findings supporting by Mutabazi et al.,2014 and Devi, 2015, who reported that most of the local farmers have low skills in rainwater harvesting technologies due to lack of exposure. However, more than 90% of the farmers in the Gairo district were not aware of the in-situ RWHTs. The type of RWH that farmers in Gairo district were familiar with is the rooftop and ridge technologies though not practised by many, while those practising it do not harvest a high quantity of water. Mwinuka et al., 2017 observed this, who reported that most of the smallholder farmers adopted tied ridge as RWH technology. These results indicate the persistent explained problem highlighting water availability problem whilst there are limited solutions within communities to different underlying problems. Singer and Shainberg, 2004 reported that semi-arid areas have poor agricultural produce due to poor availability of technologies that improve water availability.

Table 7: Barriers to investing on in-situ RWHTs in Gairo District

Variables	Categories	Ibuti	Tabuhoteli	P value
Reasons for not investing in in-situ RWH techniques	Low income	16 (33.3)	19 (39.6)	0.013*
	Lack of information	32 (66.7)	29 (60.4)	
	Poor support from the government	0 (0)	0 (0)	
	Total	48	48	
Awareness of in-situ RWHTs	Aware	3 (2.1)	8 (16.7)	0.315^{ns}
	Not aware	45 (97.9)	40 (83.3)	
	Total	48	48	

Values in parentheses are percentages *= statistical significant at $p<0.01$ and ^{ns}=not significant.

4.5: Effects of in-situ RWHTs on soil moisture storage

There was a general increase in soil moisture in all the treatments at the start of the season, followed by a decline to the end of the season. There was a significant difference ($p<0.05$) among the treatments recorded once the rainfall began to decline especially between week 9 to 10 at 0-20 cm soil depth (Fig. 4). Mulching, furrows and Zai-pits were able to conserve soil moisture for longer periods compared to TOM and TWM. Relative to TOM (control) which had 8% soil moisture, in-situ RWH technologies had more than 12 % respectively, soil moisture content.

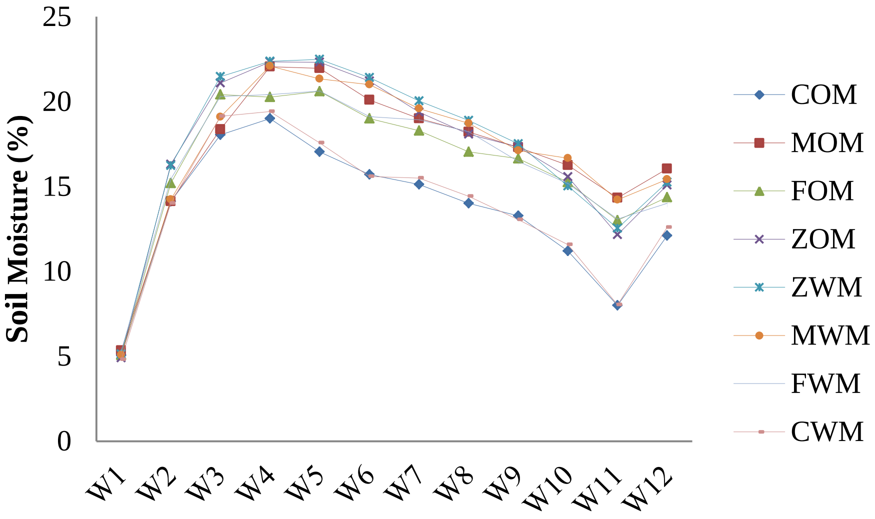

Figure 4: Soil moisture content at 0-20 cm soil depth from week 1 to week 12

Soil moisture was 10.28% in traditional cultivation (control) compared to soil moisture content of other treatments. This showed that in-situ RWH technologies were capable of storing soil moisture for a longer period because they had more than 12% soil moisture; this had showed from week 11 to week 12, soil moisture increased in all treatments because in May there was no rainfall at all while it rained little amount in June.

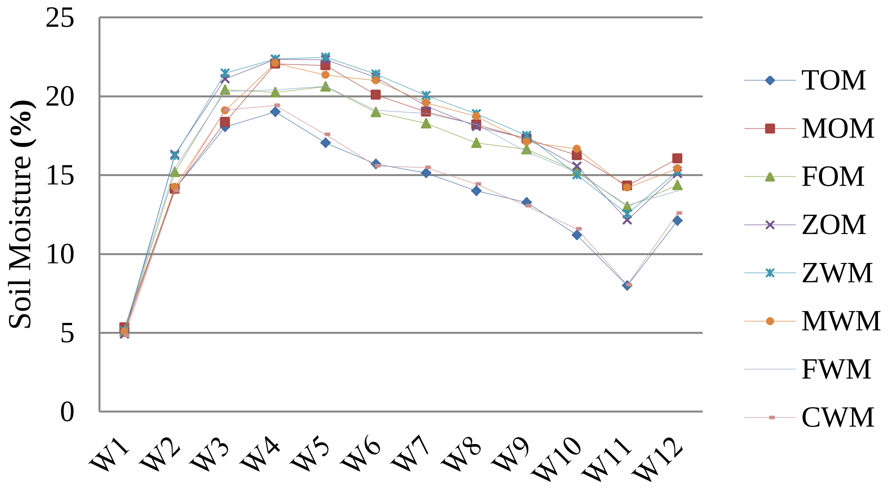

Figure 5: Soil moisture content at 20-40 cm soil depth from week 1 to week 12

The results showed that there was significant difference ($p<0.05$) between treatments in all the months (Table 8). Moisture retained in in-situ rainwater harvesting technologies with manure ranged from 20.6%-17.0% during April, 18.4-13.5% in May and 16.2%-9.7% in June. During May mulching with manure and mulching without manure had higher moisture content (18.4%) compared to control (13.5%). During June, the highest moisture content was recorded in mulching without manure (16.2%) and the lowest moisture content was recorded in the traditional cultivation with manure (9.7%) treatment.

Table 8: Mean monthly soil moisture (%) retained within 0-20 cm soil depth from April to June 2016

Treatments	**April**	**May**	**June**
TOM	17.0^c	13.5^d	10.4^f
MOM	19.1^b	18.4^a	16.2^a
FOM	19.1^b	17.4^c	14.8^d
ZOM	20.5^a	18.2^a	14.6^e
ZWM	20.6^a	18.2^a	14.6^e
MWM	19.2^b	18.4^a	16.1^b
FWM	19.2^b	18.1^b	15.0^c
TWM	17.5^c	13.6^d	9.7^g
LSD	1.026	0.350	0.0992
s.e	0.190	0.103	0.070
CV (%)	0.8	0.5	0.4
P value	0.01	0.01	0.01

TOM=Traditional cultivation, MOM=Mulching FOM=Furrow, ZOM=Zaipits, ZWM=Zai pits + manure, MWM=Mulching + manure, FWM= Furrows + manure and TWM=Traditional cultivation + manure,s.e = standard error, CV = coefficient of variation. The means with the same letter in the same column are not significantly different at 5% level of probability

Results for the second sampled layer 20-40 cm (Table 9) showed a significant difference (*p*=0.05) in moisture retention among the various treatment combinations for the complete growing period in all months. There was a decrease in moisture content from April to May and an increase from May to June 2016 (Figure 5). During April, ZOW and ZWM had significantly the highest moisture content (20.5% and 20.6%) while TOM had significantly low soil moisture content (20.4%). In May, MOM and MWM had significantly highest soil moisture content while TWM and TOM had significantly low soil moisture content. In June ZOM, ZWM, MWM and MOM had significantly highest soil moisture content while TOM and TWM had significantly lowest soil moisture content.

Table 9: Mean monthly soil moisture (%) retained within 20-40 cm soil depth from April to June 2016

Treatment	**April**	**May**	**June**
TOM	20.6^{f}	18.1^{d}	13.5^{c}
MOM	22.9^{e}	24.6^{a}	17.7^{a}
FOM	23.7^{d}	21.7^{c}	15.3^{b}
ZOM	25.9^{b}	23.7^{b}	17.4^{a}
ZWM	26.1^{a}	23.8^{b}	17.3^{a}
MWM	22.9^{e}	24.5^{a}	17.6^{a}
FWM	23.8^{c}	21.5^{c}	16.2^{b}
TWM	20.4^{g}	18.1^{d}	13.6^{c}
LSD	0.063	0.332	1.118
s.e	0.032	0.058	0.339
CV (%)	0.2	0.4	2.7
P value	0.001	0.001	0.001

TOM=Traditional cultivation, MOM=Mulching FOM=Furrow, ZOM=Zai pits, ZWM=Zai pits + manure, MWM=Mulching + manure, FWM= Furrows + manure and TWM=Traditional cultivation + manure,s.e = standard error, CV = coefficient of variation. The means with the same letter in the same column are not significantly different at 5% level of probability

In April, zai-pits were able to retain soil moisture because they harvested large quantity of rainwater compared to furrow and mulching. This also observed by Arslan et al.,2017 and Tumbo, 2003 who reported that in a semi-arid part of Tanzania, pits used as in-situ RWH technology were capable of storing soil moisture. In May, mulching had high soil moisture content compared to furrow and zai-pits because in this month there were very poor rainfall and mulching could overcome soil moisture loss caused by the presence of sunshine. Wasihun, 2013 had a similar observation and reported that mulches can store soil water for long period as well as reduction of environmental stresses. In June, mulching and Zai-pits had high soil moisture content because they managed to overcome environmental stress while pits harvested a small amount of rainfall that occurred during this month hence, increased soil moisture content again. There was a decline in soil moisture content from April to June because of the presence of a high quantity of rainfall in April and poor quantity of rainfall in May and June (Figure 3). This finding is supported by Kimani et al., 2015, who also reported that the RWH technologies have the ability to harvest the amount of rainfall. Moreover, this study showed that the amount of moisture content in the soil depends on the amount of rainfall received as well as the ability of storage because mulch tended to preserve moisture than the other two technologies (pits and furrows). However, Cai et al., 2015 indicated that the use of straw mulch can have similar outcomes to grass mulch possibly because of high soil moisture storage.

The variation in soil moisture content with soil depths was due to different factors such as the amount of rainfall; this also observed by Karuma et al., 2015 who reported that soil moisture content depends on soil depth and environmental conditions. This study showed that there was no relationship between organic manure and soil moisture storage because the technologies with manure had the lowest soil moisture content compared with technologies without manure (Table 7 and 8). A similar finding reported by Achieng et al., 2010 in western Kenya and Aniekwe and Nwokwe (2015) in south-eastern Nigeria indicted that organic manure and soil moisture content are inversely proportional.

4.7 Effect of in-situ RWHTs on maize height

Results showed that during vegetative to tasseling stages, there was a significant difference ($p<0.05$) in maize height among the treatments for the entire growing period (Table 10). At the emergence stage all treatments had a similar height; mulching without manure, mulching with manure and traditional cultivation with manure compared to control because at that stage mulches were not yet applied to the plots (Fig 6). At the vegetative stage with leaves five (V5) farrow with manure, furrow without manure, zai-pit with manure and mulching with manure had significantly, highest maize height compared to other treatments. At Vegetative, stage with eight leaves (V8) zai-pit with manure, zai-pit without manure and furrow with manure had significantly highest maize plant height compared to other treatments. At the vegetative stage with eleven leaves (V11) mulching with manure, mulching without manure, zai-pit with manure and zai-pit without manure had significantly highest maize plant height compared to other treatments. At the vegetative stage with thirteen leaves (V13) zaipit- with manure, zai-pit without manure, furrow with manure and furrow without manure had significantly highest maize plants compared to other treatments. At Tasselling stage (VT) there was no significant difference pronounced because all in-situ RWHTs had similar means.

Table 10: Mean Maize height (cm) at vegetation to tasseling stages for April-June 2016

Treatments	V5	V8	V11	V13	VT
TOM	25.5^{d}	94.7^{c}	122.3^{c}	181.1^{c}	249.2^{b}
MOM	31.0^{b}	106.3^{b}	161.3^{a}	206.7^{b}	259.3^{a}
FOM	32.3^{a}	101.7^{b}	145.7^{b}	204.4^{b}	263.0^{a}
ZOM	31.5^{b}	121.2^{a}	171.2^{a}	224.4^{a}	256.7^{a}
ZWM	33.0^{a}	$123 .0^{a}$	167.7^{a}	231.0^{a}	277.2^{a}
MWM	34.1^{a}	113.1^{b}	183.1^{a}	215.71^{a}	291.3^{a}
FWM	33.3^{a}	127.1^{a}	154.7^{b}	214.3^{a}	271.7^{a}
TWM	27.0^{c}	101.0^{b}	137.8^{b}	193.7^{b}	250.7^{b}
LSD	1.874	9.75	13.70	17.09	21.27
s.e	0.349	2.52	0.49	7.26	4.83
CV (%)	1.1	2.2	0.3	3.5	1.8
P value	0.001	0.001	0.001	0.001	0.001

TOM= Traditional cultivation, MOM=Mulching FOM=Furrow, ZOM=Zai pits, ZWM=Zai pits + manure, MWM=Mulching + manure, FWM= Furrows + manure and TWM=Traditional cultivation + manure, s.e = standard error, CV = coefficient of variation. The means with the same letter in the same column are not significantly different at 5% level of probability (Duncan's Multiple Range Test). V5= Vegetative (five leaves), V8=Vegetative (eight leaves), V11= Vegetative stage leaves eleven, V=13 Vegetative stage leaves thirteen and VT= Tasselling stage

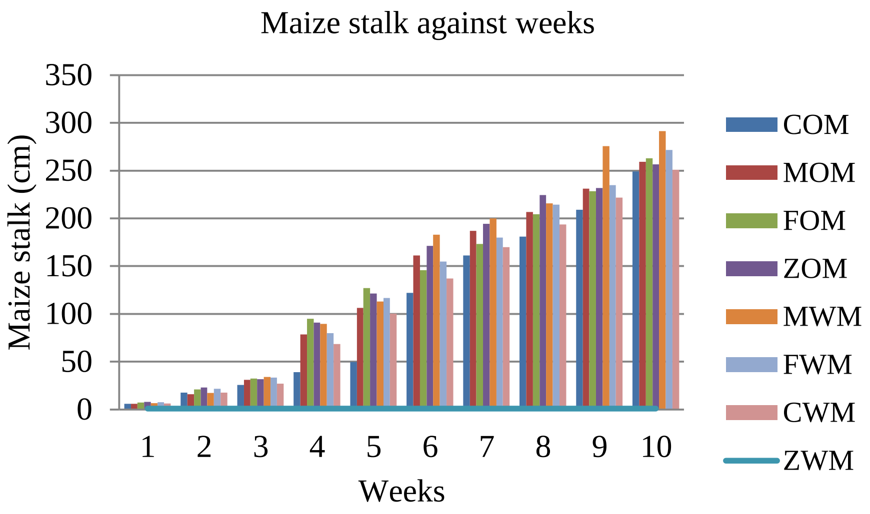

Figure 6: Maize stalk growth from week 1 to week 10 of the completely growing season of maize at different treatments.

Mulching, furrows and zai-pits containing a high amount of soil moisture had the highest crops height. Plant height and moisture content showed a relationship because treatments with high moisture levels had the tallest plants. However, higher maize height under the plots with mulching could have been because of mulching that helped high infiltration and retention of water for long period. The higher maize crop height in zai-pits with manure, furrow with manure, furrow without manure and zai-pits without manure was because the pits and furrow harvested high quantity of rainwater that helped in the transportation of nutrients from soil to the crop. Gicheru et al., (2004) and Karuma et al.,2014 also reported the same observation that the availability of soil moisture reflects the growth rate of the crops. Moreover, there was a strong relationship between manure and in-situ RWHTs because the integration of the two, results in high yield. This finding is supported by the observations made by Buhman et al., 2004; Findeling et al., 2003 and Gary and Kincaid, 2007, who indicated that manure helps to improve soil properties by increasing soil nutrients thus maize grown in that soil has a good growth rate.

4.8: Effects of in-situ RWHTs on maize performance

Results showed that in-situ RWH technologies significantly ($p<0.05$) influenced maize grain yields (Table 11). Comparatively, traditional cultivation without manure had significantly lowest maize grain yield (3.2 t ha^{-1}). However, Biomass yield results showed that all treatments were statistically different ($p<0.05$). Moreover, mulching with manure had significantly the highest biomass yield (6.2 t ha^{-1}) compared to other treatments while traditional cultivation with manure had significantly the lowest biomass yield (4 t ha^{-1}) compared to other treatments.

Table 11: In-situ RWHTs and maize performance

Treatments	Biomass weight (t ha^{-1})	Grain weight (t ha^{-1})
TOM	3.4^{c}	3.2^{b}
MOM	4.5^{b}	4.4^{a}
FOM	5.2^{b}	5.0^{a}
ZOM	4.7^{b}	4.2^{a}
ZWM	5.0^{b}	4.8^{a}
MWM	6.2^{a}	5.1^{a}
FWM	4.7^{b}	4.6^{a}
TWM	3.9^{c}	3.4^{b}
LSD	0.981	0.981
s.e	0.45	0.352
CV (%)	13.2	8.2
P value	0.01	0.01

Key: TOM=Traditional cultivation, MOM=Mulching FOM=Furrow, ZOM=Zaipits, ZWM=Zai pits + manure, MWM=Mulching + manure, FWM= Furrows + manure and TWM=Traditional cultivation + manure,s.e = standard error, CV = coefficient of variation. The means with the same letter in the same column are not significantly different at 5% level of probability

From this study, it was found that the highest grain yield was because of the high moisture content. Thus, there were strong relationships between soil moisture retained by the technologies and grain yield. This was also observed by Mmbaga and Lyamchai (2001) who reported that furrows and ridges technologies had high crop productivity in Rwanda. Also Msita et al., 2010 reported mulching was able to improve productivity in drier parts of Africa. However, all in-situ RWHTs produced maize grain yield of more than 4 t/ha, where furrow produced maize grain yield between 4.6 to 5.0 t/ha, zai-pits produced maize grain yield between 4.2 to 4.8 t/ha and mulching produced maize grain yield between 4.4 to 5.1 t/ha. Moreover, there was a strong relationship between organic manure and in-situ-RWHTs because the integration between the two produced high yield MWM (5.1 t/ha)>MOM (4.4 t/ha) and ZWM (4.8)>ZOM (4.2). Mati, (2005); Malligawad, 2010; Hue and Silva (2000) also had similar results, who reported that manure could double the yield since the soil with organic manure become more fertile than soil without organic manure. However, there was a difference because furrow without manure had the highest maize grain yield compared to the furrow with manure. This is possibly because it increased water holding capacity and decreased runoff, thus improved soil moisture content hence increase grain yield.

From this study, it was observed that crops with the highest heights produced the highest biomass yield. This is because the tallest crops were healthy because of the high soil moisture content. This finding is supported by Hansen et al., 2012 who reported that RWH technologies in any semi-arid area produce high biomass yield. However, all the in-situ RWHTs had a biomass yield of more than 4.0 t/ha. Although there was a strong relationship between manure and in-situ RWHTs, integration of the two produced high biomass yield ZWM (5.0 t/ha) >ZOM (4.7 t/ha) and MWM (6.2 t/ha) >MOM (4.5 t/ha). A similar study conducted in Ethiopia as well as in Kenya and found out that RWH technologies could improve yield by about 73% (Achieng et al., 2010; Oloro et al., 2007). A study conducted in Zimbabwe reported that under in situ rainwater harvesting technologies and organic manure biomass yields were increased (Braul and Woodring, 2011)

This study found out that the amount of rainfall received by in–situ RWH technologies had great impacts on the maize plant. During short rainfall (Figure 3) there were a prolonged drought period, which caused wilting of maize plant at the vegetative stage, and resulted in crop failure. It is reported that in eastern Africa, water scarcity is the major cause of poor crop production (Magehema, 2014) while the availability of rainfall has both positive and negative impacts on grain yield and biomass yield.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Smallholder farmers in Gairo District have limited options of coping strategies during water scarcity due to limited knowledge on other technologies that can assist them in crop production. The farmers mainly depend on planting drought-resistant crops while others stop farming activities when there is a water scarcity impact. Coping strategies like planting zai-pits, planting furrows and mulching as alternative ways of improving soil moisture and yield are still unpopular among farmers in Gairo District.

In-situ RWH technologies were confirmed to increase soil water under different soil depth profiles compared to traditional cultivation. However, mulching with and without manure retained more soil moisture compared with planting Furrow and planting zai-pit.

The integration of zai-pits, furrows, mulches with organic manure increased grain and biomass yields compared to traditional cultivation. While mulching with manure had the highest biomass and grain yield compared with planting furrows and planting zai-pits.

5.2 Recommendations

From this study, the following is made in order to broaden the scope of coping strategies and increasing maize productivity in Gairo District;

It is recommended that both men and women be empowered through workshops, seminars and field demonstrations, specifically training of farmers on other water-shortage coping strategies to reduce overreliance on traditional methods.

Researchers, extension service providers and other stakeholders in agriculture should engage in concerted efforts by promoting the combination of in-situ rainwater harvesting technologies with manure in order to improve productivity and minimise the problem of food shortage.

It is also recommended that integrated in-situ RWHTs and manure be adopted as the best technologies for smallholder farmers as they have been proved to retained more soil moisture as well as provided the highest yield.

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APPENDICES

Appendix 1: Household Questionnaire

To assess the existing in-situ RWH techniques and measures to overcome water scarcity

General information

Mobile phone of Household Head …………………………….

1) Sample No……………………Village of household………………………………
2) Gender of respondent:
    a) Man (…);
    b) Women (…)
3) Family position of respondent ……………
4) Education level of respondent
    a) None ( ),
    b) Primary ( );
    c) Secondary ( ),
    d) Tertiary ( )
5) Age of respondent ……..yrs
6) Livestock numbers:
    a) Cattle……………
    b) Goats…………
    c) sheep……..
    d) Donkeys………..
    e) others
7) Total family size……………………….
8) How many adults work on the farm……….
9) Occupation of the spouses …

a) Both working on the farm ( )
b) Both working off farm ( )
c) male mainly working on farm ( )
d) Female mainly working off farm ( )

10) What proportion does off farm income contribute to household income……..

a) < 30% ( )
b) 31- 60% ( )
c) 3. 61- 90% 4 ( )
d) > 90% ( )

11) Total arable land (acres/hectares)…………

12) Total land cultivated for crop production (acres/hectares)…………

13) List your three major crops in order of priority

a) …………………
b) ………………..
c) ………………

1) Sources of water for agricultural activities

a) Rainfall ( );
b) Rivers ( );
c) Lakes ( );
d) Others (Specify) ( )

14) How could you charge the repute of water availability for agriculture activities? (Tick appropriately)

a) Very adequate ( );
b) Adequate ( );
c) Scarce ( );
d) extremely scarce ( )

15) Have you been visited by Agricultural Extension officers in the last two year

   a) Yes
   b) No

16) If Yes Did they advise you on rain water harvesting……….
    a) Yes ( )
    b) No ( )

17) Have ever participated in any social group…………..
    a) Yes ( )
    b) No ( )

18) If Yes: Do you discuss rain water harvesting during group meetings……
    a) Yes ( )
    b) No ( )

19) How does scarcity of water affect productivity?
    a) Low productivity ( );
    b) Poor productivity ( );
    c) Very poor productivity ( )

20) How do you cope with water scarcity as a farmer?
    a) Conducting irrigation system ( );
    b) Planting drought resistance crops ( );
    c) Stopping farming system ( );
    d) d. Others ( )

21) What are the causes of persistent water scarcity in your farm.
    a) Climate Change ( );
    b) Lack of sources of water ( );
    c) Competition among water users ( );
    d) others ( ) .

22) . Do you practice any In-situ rainwater harvesting techniques in maize production?
    a) Yes ( );

b) No ( )

23) . If yes please list them

a) Pitting ( );
b) Mulching ( );
c) tied ridges ( );
d) Zero tillage ( );
e) Other ( ).

24) How would you rate the importance of numerous In-situ RHTs you practice in maize production?

In-situ rainwater harvesting techniques	Very high	high	Fairly high	low	very low
a. Pitting					
b. Mulching					
c. Tied ridges					
d. Zero tillage					
e. Other					

25) What are your reasons for liking In-situ RHTs and maize performance?

In-situ rainwater harvesting techniques	Reasons a.Very high productivity b. High productivity c. Low productivity; b. Poor productivity ; c. Very poor productivity
i. Pitting	
ii. Mulching	
iii. tied ridges	
iv. zero tillage	

26) Extent of use of water harvesting in maize production

In-situ rainwater harvesting techniques	How much land is under
i. Pitting	
ii. Mulching	
iii. tied ridges	
iv. zero tillage	
v. others	

27) What are the motives that prevent you from participating in In-situ rainwater harvesting techniques that could improve your water situation?

   a) Low income ( );
   b) Poverty ( );
   c) Poor support from the government ( );
   d) Lack of knowledge about the techniques ;
   e) Others ( )

28) What role do you think you can play as an individual to decrease the factors mentioned above?

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29) What can be done to overcome the problem of water scarcity in your area?

   a) Conducting irrigation system ( );
   b) Water harvesting system ( );
   c) Others ( )

30) Which stakeholders do you think can play an essential position in helping to cope with network water issues?

Stakeholders	Main Role (s)
1. Government	
2. Community members	
3. Individual farmers	
4. Professionals	
5. Civil society	
6. Private sector	
7. Specify others	

Appendix 2: Key In-depth Informant

Questionnaire designed for the government ministry staff and NGO's.

1) Sample No………………….
   District……………………village …………………………
2) Sex…
   a) Female ( );
   b) Male ( )
3) What are the major causes of water scarcity in this area?
   a) Climate Change ( );
   b) Lack of sources of water ( );
   c) Competition among water users ( );
   d) others ( )
4) How do you think the causes above can be solved?
   a) Conducting irrigation system ( );
   b) Water harvesting system ( );
   c) Educating farmers ( );
   d) Others ( )

5) What do humans do in this location to get water in case the water shortage has persisted for an extended?
   a) Conducting irrigation system ( );
   b) Planting drought resistance crops ( );
   c) c Stopping farming system ( );
   d) d. Others ( )

6) Which type of In situ rainwater harvesting people practiced in this area?
    a) Pitting ( );
    b) Mulching ( );
    c) Furrow ( );
    d) Contour Bunds ( );
    e) Deep tillage ( );
    f) Other ( ).

7) How can you compare the types mentioned above with Maize performance?
    a) Very high ( );
    b) High ( );
    c) Low ( );
    d) Very low ( )

8) What factors do you think hinder the investment In situ rainwater harvesting techniques in this area?
    a) Low income ( );
    b) Poverty ( );
    c) Poor support from the government ( );
    d) Lack of knowledge about the technology;
    e) Others ( )

9) What role do you suspect you may play as an man or woman or employer to reduce the factors stated above?

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Appendix 3: ANOVA Table for soil moisture content (%) in April at 0-20cm

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	49.6753	7.0965	20.66	001
Blocks	2	0.5777	0.2888	0.84	0.012
Error	14	4.8091	0.3435		
Total	23	55.0620			

Appendix 4: ANOVA Table for soil moisture content (%) in May at 0-20cm

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	69.16	9.88	32.34	0.000
Blocks	2	1.52	0.76	2.49	0.012
Model	9	70.68	7.85	25.70	0.00
Error	14	4.28	0.31		
Total	23	74.96			

Appendix 5: ANOVA Table for soil moisture content (%) in June at 0-20cm

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	87.59	12.51	32.75	0.000
Blocks	2	0.61	0.30	0.79	0.47
Model	9	88.20	9.80	25.65	0.00
Error	14	5.35	0.38		
Total	23	93.55			

Appendix 6Appendix 7: Table for soil moisture content (%) in April at 20-40cm

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	47.68	7.10	20.66	0.000
Blocks	2	0.58	0.29	0.84	0.452
Model	9	50.26	5.58	16.25	0.00
Error	14	4.81	0.34		
Total	23	55.06			

Appendix 8: ANOVA Table for soil moisture content (%) in May at 20-40cm

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	121.51	17.36	433.70	0.000
Blocks	2	0.17	0.09	2.14	0.155
Model	9	121.69	13.52	337.80	0.00
Error	14	0.56	0.04		
Total	23	122.24			

Appendix 9: ANOVA Table for soil moisture content (%) in June at 20-40cm

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	62.51	8.93	2780.85	0.000
Blocks	2	0.09	0.04	12.22	0.000
Model	9	62.60	6.95	2165.60	0.000
Error	14	0.04	0.00		
Total	23	62.63			

Appendix 10: ANOVA Table for V5 (cm)

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	202.57	28.91	25.25	0.000
Blocks	2	1.95	1.00	0.85	0.045
Model	9	204.31	22.70	19.83	0.000
Error	14	16.03	1.14		
Total	23	220.33			

Appendix 11: ANOVA Table for V8 (cm)

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	383.50	383.50	12.37	0.00
Blocks	2	50.75	50.75	1.646.16	0.23
Model	9	2786.01	309.56	9.99	0.00
Error	14	433.89	30.99		
Total	23	3219.89			

Appendix 12: ANOVA Table for V11 (cm)

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	8102.15	1157.45	18.90	0.00
Blocks	2	3.80	1.90	0.03	0.97
Model	9	8105.95	900.66	14.71	0.00
Error	14	857.39	61.24		
Total	23	8963.34			

Appendix 13 ANOVA Table for V13 (cm)

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	8102.16	786.55	8.26	0.00
Blocks	2	422.12	422.12	4.43	0.03
Model	9	6350.07	705.56	7.41	0.00
Error	14	1332.10	95.21		
Total	23	7683.04			

Appendix 14: ANOVA Table for VT (cm)

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	6146.48	878.07	5.95	0.00
Blocks	2	372.82	186.41	1.26	0.31
Model	9	6519.30	724.37	4.91	0.00
Error	14	2065.56	147.54		
Total	23	8584.86			

Appendix 15: Contrast between treatments

Contrast	**DF**	**Contrast SS**	**Mean Square**	**F Value**	**Pr > F**
1 vs 2	1	45.3750000	45.3750000	39.64	<.0001
1 vs 3	1	69.7686000	69.7686000	60.94	<.0001
1 vs 4	1	54.7224000	54.7224000	47.80	<.0001
1 vs 5	1	84.6001500	84.6001500	73.90	<.0001
1 vs 6	1	111.7153500	111.7153500	97.59	<.0001
1 vs 7	1	91.4941500	91.4941500	79.92	<.0001
1 vs 8	1	3.3750000	3.3750000	2.95	0.1080
2 vs 3	1	2.6136000	2.6136000	2.28	0.1530
2 vs 4	1	0.4374000	0.4374000	0.38	0.5464
2 vs 5	1	6.0601500	6.0601500	5.29	0.0373

Contrast	**DF**	**Contrast SS**	**Mean Square**	**F Value**	**Pr > F**
2 vs 6	1	14.6953500	14.6953500	12.84	0.0030
2 vs 7	1	8.0041500	8.0041500	6.99	0.0192
2 vs 8	1	24.0000000	24.0000000	20.96	0.0004
3 vs 4	1	0.9126000	0.9126000	0.80	0.3870
3 vs 5	1	0.7141500	0.7141500	0.62	0.4428
3 vs 6	1	4.9141500	4.9141500	4.29	0.0572
3 vs 7	1	1.4701500	1.4701500	1.28	0.2762
3 vs 8	1	42.4536000	42.4536000	37.08	<.0001
4 vs 5	1	3.2413500	3.2413500	2.83	0.1146
4 vs 6	1	10.0621500	10.0621500	8.79	0.0102
4 vs 7	1	4.6993500	4.6993500	4.10	0.062

Contrast	**DF**	**Contrast SS**	**Mean Square**	**F Value**	**Pr > F**
					3
5 vs 6	1	1.8816000	1.8816000	1.64	0.2207
5 vs 7	1	0.1350000	0.1350000	0.12	0.7364
5 vs 8	1	54.1801500	54.1801500	47.33	<.0001
6 vs 7	1	1.0086000	1.0086000	0.88	0.3638
6 vs 8	1	76.2553500	76.2553500	66.61	<.0001
7 vs 8	1	59.7241500	59.7241500	52.17	<.0001

Appendix 16: LSM

Least Squares Means for Effect Tr

i	**j**	**Difference Between Means**	**Simultaneous 95% Confidence Limits for LSMean(i)-LSMean(j)**	
1	**2**	-11.780000	-27.819002	4.259002
1	**3**	-16.116667	-32.155669	-0.077664
1	**4**	-26.660000	-42.699002	-10.620998
1	**5**	-28.450000	-44.489002	-12.410998
1	**6**	-18.540000	-34.579002	-2.500998
1	**7**	-32.566667	-48.605669	-16.527664
1	**8**	-6.450000	-22.489002	9.589002
2	**3**	-4.336667	-20.375669	11.702336
2	**4**	-14.880000	-30.919002	1.159002
2	**5**	-16.670000	-32.709002	-0.630998
2	**6**	-6.760000	-22.799002	9.279002
2	**7**	-20.786667	-36.825669	-4.747664
2	**8**	5.330000	-10.709002	21.369002
3	**4**	-10.543333	-26.582336	5.495669
3	**5**	-12.333333	-28.372336	3.705669
3	**6**	-2.423333	-18.462336	13.615669
3	**7**	-16.450000	-32.489002	-0.410998

Least Squares Means for Effect Tr

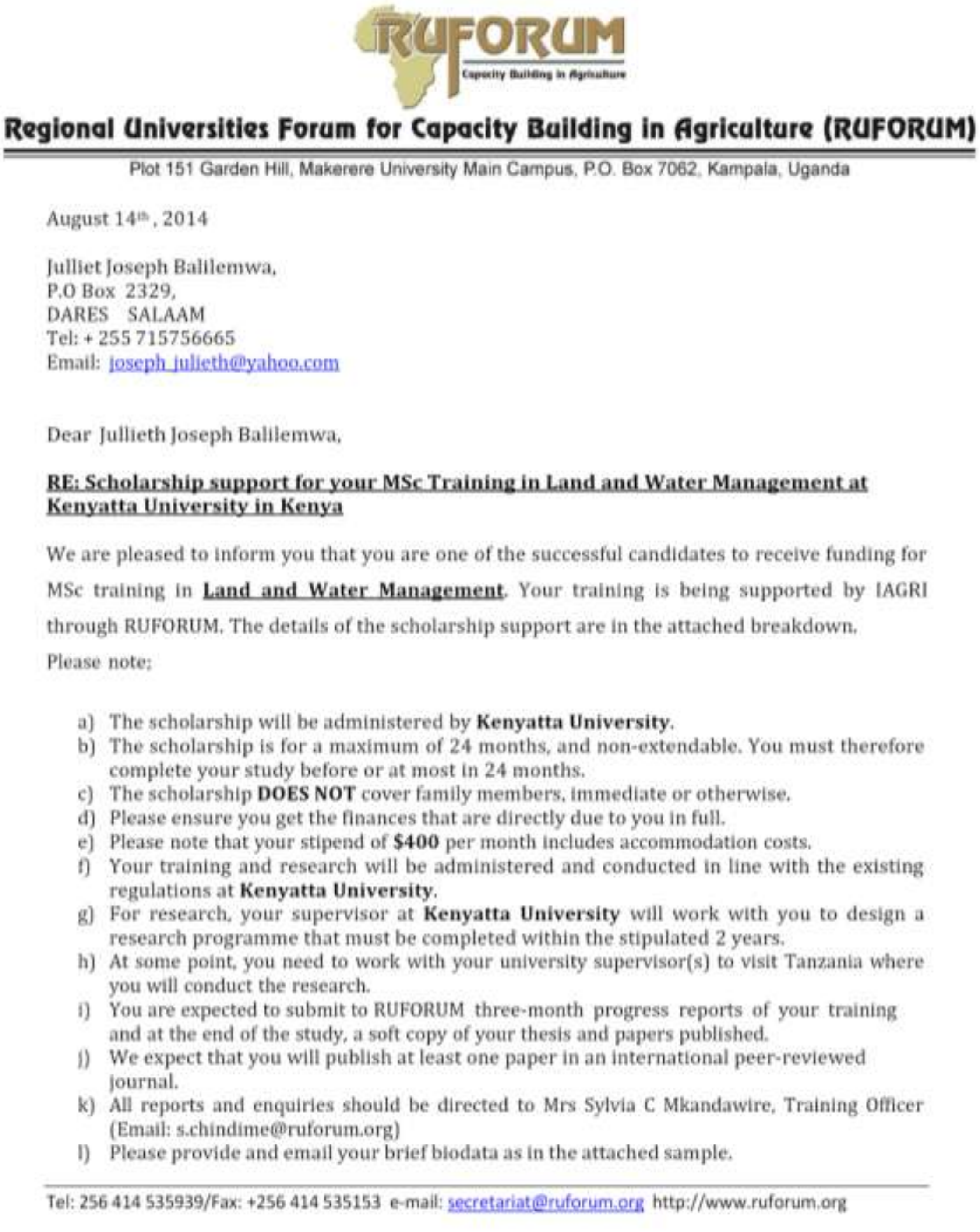
i	j	Difference Between Means	Simultaneous 95% Confidence Limits for LSMean(i)-LSMean(j)	
3	**8**	9.666667	-6.372336	25.705669
4	**5**	-1.790000	-17.829002	14.249002
4	**6**	8.120000	-7.919002	24.159002
4	**7**	-5.906667	-21.945669	10.132336
4	**8**	20.210000	4.170998	36.249002
5	**6**	9.910000	-6.129002	25.949002
5	**7**	-4.116667	-20.155669	11.922336
5	**8**	22.000000	5.960998	38.039002
6	**7**	-14.026667	-30.065669	2.012336
6	**8**	12.090000	-3.949002	28.129002
7	**8**	26.116667	10.077664	42.155669

Appendix 17: ANOVA Table for Biomass Yield (kg)

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	8.3932	1.1990	1.46	0.260
Blocks	2	3.2552	1.6276	1.98	
Error	14	11.5365	147.54		
Total	23	8584.86			

Appendix 18: ANOVA Table for Grain yield (kg)

Source of variation	d.f.	s.s.	m.s.	F-value	F pr.
Treatments	7	.2430	1.4633	4.66	0.007
Blocks	2	1.9940	0.9970	3.18	
Error	14	4.3949	4.3949		
Total	23	16.6319			



RUFORUM
Capacity Building in Agriculture

Regional Universities Forum for Capacity Building in Agriculture (RUFORUM)

Plot 151 Garden Hill, Makerere University Main Campus, P.O. Box 7062, Kampala, Uganda

August 14th , 2014

Julliet Joseph Balilemwa,
P.O Box 2329,
DARES SALAAM
Tel: + 255 715756665
Email: joseph_julieth@yahoo.com

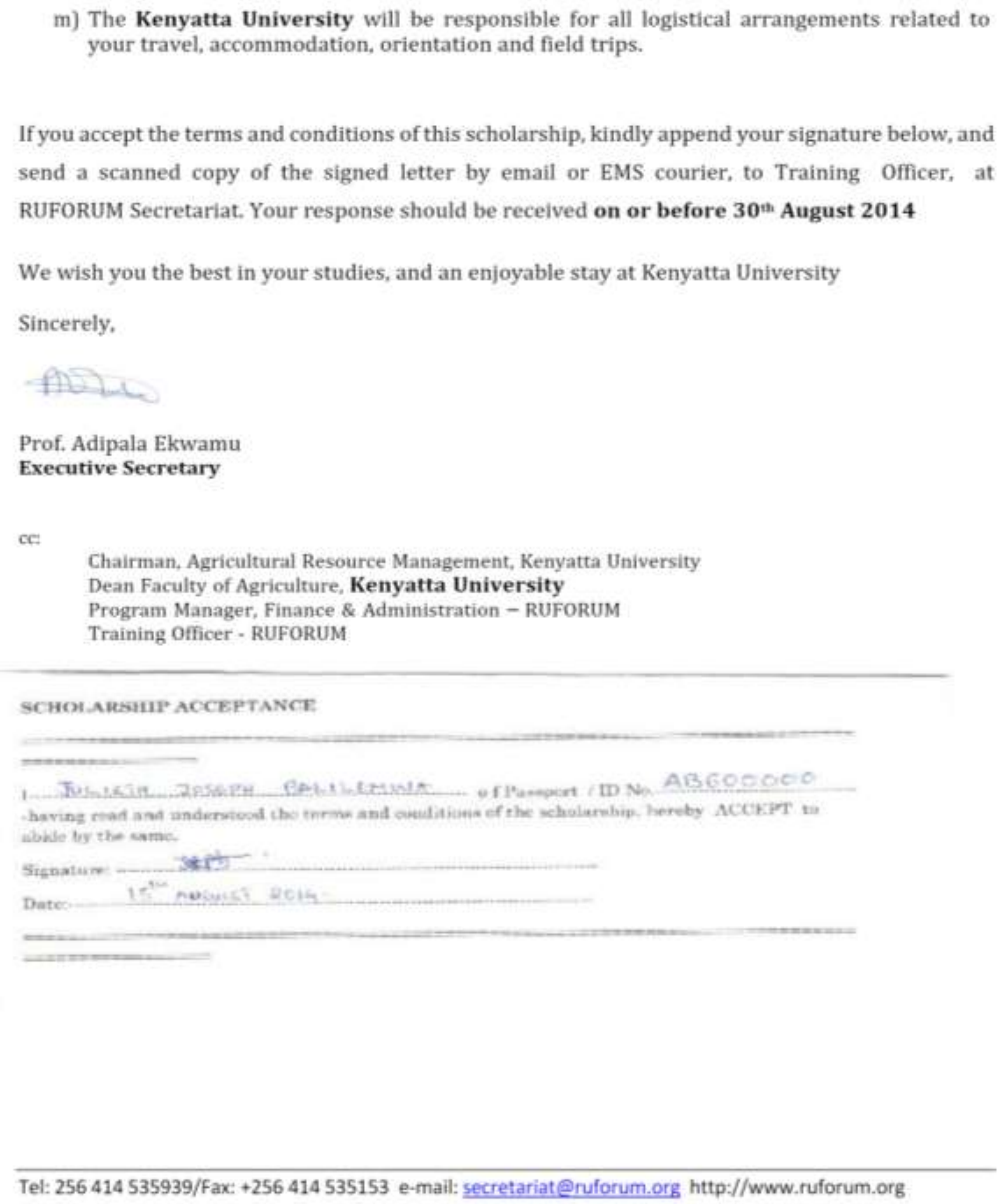
Dear Jullieth Joseph Balilemwa,

RE: Scholarship support for your MSc Training in Land and Water Management at Kenyatta University in Kenya

We are pleased to inform you that you are one of the successful candidates to receive funding for MSc training in **Land and Water Management**. Your training is being supported by IAGRI through RUFORUM. The details of the scholarship support are in the attached breakdown.

Please note;

a) The scholarship will be administered by **Kenyatta University**.
b) The scholarship is for a maximum of 24 months, and non-extendable. You must therefore complete your study before or at most in 24 months.
c) The scholarship **DOES NOT** cover family members, immediate or otherwise.
d) Please ensure you get the finances that are directly due to you in full.
e) Please note that your stipend of **$400** per month includes accommodation costs.
f) Your training and research will be administered and conducted in line with the existing regulations at **Kenyatta University**.
g) For research, your supervisor at **Kenyatta University** will work with you to design a research programme that must be completed within the stipulated 2 years.
h) At some point, you need to work with your university supervisor(s) to visit Tanzania where you will conduct the research.
i) You are expected to submit to RUFORUM three-month progress reports of your training and at the end of the study, a soft copy of your thesis and papers published.
j) We expect that you will publish at least one paper in an international peer-reviewed journal.
k) All reports and enquiries should be directed to Mrs Sylvia C Mkandawire, Training Officer (Email: s.chindime@ruforum.org)
l) Please provide and email your brief biodata as in the attached sample.



m) The **Kenyatta University** will be responsible for all logistical arrangements related to your travel, accommodation, orientation and field trips.

If you accept the terms and conditions of this scholarship, kindly append your signature below, and send a scanned copy of the signed letter by email or EMS courier, to Training Officer, at RUFORUM Secretariat. Your response should be received **on or before 30th August 2014**

We wish you the best in your studies, and an enjoyable stay at Kenyatta University

Sincerely,

Prof. Adipala Ekwamu
Executive Secretary

cc:

Chairman, Agricultural Resource Management, Kenyatta University
Dean Faculty of Agriculture, **Kenyatta University**
Program Manager, Finance & Administration – RUFORUM
Training Officer - RUFORUM

SCHOLARSHIP ACCEPTANCE

I [illegible] JOSEPH [illegible] of Passport / ID No. AB6000000

-having read and understood the terms and conditions of the scholarship, hereby ACCEPT to abide by the same.

Signature:

Date: 15th AUGUST 2014

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