

**RAINWATER HARVESTING PRACTICES, CROPPING SYSTEMS AND
PRODUCTIVITY IN SMALLHOLDER FARMS IN LAIKIPIA CENTRAL
DISTRICT**

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DECLARATION

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

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TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	3
1.2.1 Justification.....	4
1.3 Study objectives.....	5
1.3.1 Overall objective	5
1.3.2 Specific objectives.....	5
1.3.3 Research questions	5
CHAPTER TWO: LITERATURE REVIEW.....	6
2.1 Small scale farming in Kenya.....	6
2.2 Cropping systems	7
2.3 Rain water harvesting	9
2.3.1 Rainfed agriculture and water stress.....	9
2.3.2 Water harvesting for improved rainfed agriculture	10
2.3.3 Challenges in adoption of RWH.....	14
2.3.4 Maximizing benefits of supplemental irrigation.....	15
CHAPTER THREE: MATERIALS AND METHODS	17
3.1 Description of Study area	17
3.2 Study approach.....	20
3.2.1 Survey.....	20
3.2.2 Gross margin analysis.....	22
3.3 Data analysis.....	22
4.1 Rain water harvesting technologies	23
4.1.2 Benefits associated with the adoption of RWH technologies.....	28
4.2 Crops grown and cropping systems under rain water harvesting	31
4.2.1 Crops grown under RWH.....	31
4.2.2 Cropping systems	34

4.3 Crop productivity for households with and without RWH systems	38
4.3.1 Major food crops	38
4.3.2 Vegetable crops	42
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS.....	50
5.1 Conclusions	50
5.2 Recommendations	50
REFERENCES	51
APPENDIX	59
Appendix 1 Questionnaire used in the study	59
Appendix 2 Long term rainfall data (1943-2010) from Lengetia farm	64
Appendix 3 Daily rainfall (mm)for Matanya, 2003-2011	67
Appendix 4 Pan evaporation data for Matanya Met. Station: 2009-2010	80
Appendix 5- Chi-square test on adoption of water pans in the study area.	81
Appendix 6 Crop Production Statistics for Laikipia Central.....	81

LIST OF TABLES

Table 3.1 Target farm holdings in the four study blocks.....	21
Table 4.1 Coping strategies adopted by farmers against rainfall shortage.....	23
Table 4.2 Characteristics of water pans in Matanya.....	26
Table 4.3 Benefits of rainwater harvesting	29
Table 4.4 Factors influencing choice of RWH technology among farmers in Matanya	30
Table 4.5 Type of crops grown under RWH in Matanya	32
Table 4.6 Type of crops under different RWH technologies in Matanya.....	33
Table 4.7 Descriptive statistics of small-holder farmers in Matanya	34
Table 4.8 Source of water for irrigation in Matanya.	35
Table 4.9 Factors influencing choice of crops to irrigate in Matanya.	36
Table 4.10 Type of crops that farmers irrigate in Matanya.....	37
Table 4.11 Average yields (kg/ha) for the major food crops during the 2011 short rains in Matanya.....	38
Table 4.12 Variability of maize yields among farmers practicing and those not practicing RWH in Matanya	39
Table 4.13 Analysis of the yield differences for the three major crops in Matanya.....	40
Table 4.14 Gross margin analysis for maize production with and without RWH technologies	41
Table 4.15 Analysis of the mean yield differences for the three vegetable crops in Matanya	42
Table 4.16 Water conveyance and application methods in Matanya.	43
Table 4.17 Gross margin analysis for tomatoes and cabbages under furrow irrigated from a 100m³ water pan in Matanya.....	46
Table 4.18 Return to investment from a 100m³ water pan for tomato production in Matanya.....	47

LIST OF FIGURES

Figure 3.1 Location of study area (Source: CETRAD, 2011)	18
Figure 4.1 Rain water harvesting technologies in Matanya	24
Figure 4.2 Cropping systems prevalent in Matanya	34

LIST OF PLATES

Plate 4.1 Water pan lined with polythene sheet to reduce seepage loss	28
Plate 4.2 Tomato production from a low head drip irrigation system installed next to a water pan in Matanya.	44
Plate 4.3 A successful RWH technology farmer's green house and water pan.....	49

LIST OF ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi-Arid Lands
ASDS	Agricultural Sector Development Strategy
CA	Conservation Agriculture
CEEPA	Centre for Environmental Economics and Policy in Africa
CETRAD	Center for Training and Integrated Research in ASAL and Development
CoV	Coefficient of Variance
CT	Conservation Tillage
ENSO	El-Niño Southern Oscillation (ENSO)
FADC	Focal Areas Development Committee
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GHA	Great Horn of Africa
GM	Gross Margin
HYV	High Yielding Varieties
ICRAF	International Center for Research in Agro-Forestry
KMD	Kenya Meteorological Department
KNBS	Kenya National Bureau of Statistics
KSh	Kenya Shilling
LRP	Laikipia Research Programme
MoA	Ministry of Agriculture
MDG	Millennium Development Goal
NALEP	National Agriculture and Livestock Extension Programme
RELMA	Regional Land Management Unit
RW	Rain water
RWH	Rain-water harvesting

SD	Standard Deviation
SI	Supplemental Irrigation
SRA	Strategy for Revitalizing Agriculture
US\$	United States Dollar
UV	Ultra Violet
WHO	World Health Organisation
WRMA	Water Resource Management Authority
WUA	Water User Associations
SSA	Sub Sahara Africa

ABSTRACT

Over dependence on rainfed agriculture is one of the major problems in Kenya's agricultural sector. One of the most promising solutions is upgrading rainfed agriculture through the adoption of rainwater harvesting (RWH) and its management which will improve water availability for productive purposes. However, what is not clear is the role of rainwater harvesting on household food security and the returns to the investment in the water management systems in semi-arid lands. This study evaluated smallholder farms in Matanya Location which is an area that is prone to drought. The overall objective was to document rainwater harvesting practices, cropping systems and crop productivity by smallholder farmers in Laikipia Central District. A survey was carried out using a structured questionnaire on 100 households. Data obtained was analyzed using the Statistical Package for Social Scientists (SPSS).

Adoption of rain water harvesting significantly increased crop yields. The average maize yield in farms with RWH (259 kg/ha) was 14 times more than farms not having RWH which was 18 kg/ha. For vegetable crops, the average yields increased from 4.6 to 9.9 t/ha for spinach, 4.8 to 12.5 t/ha for kales and 4.2 to 10.5 t/ha for garden peas. Though the vegetable yields were more than double for farms with RWH, it is only in garden peas that the yield difference was significant (p value less than 0.05). All the 100% farmers investing in on-farm rainwater storage preferred to irrigate vegetable crops during the dry season while only 35% irrigated during the rainy season. The crops grown during the dry season fetched a premium price in the market. Availability of harvested rainwater for irrigation from water pans had led to a shift from subsistence to commercial farming. The survey found out that the waterpan capacity ranged from 50 to 100m³ and 50% suffered from seepage losses. Due to the limited stored water; farmers were shifting from the use of the furrow water application method to the efficient drip irrigation method. Farmers adopting the drip irrigation reported higher yields for tomatoes and cabbages. Few economically well-off farmers were lining their waterpans with UV resistant plastic material to reduce seepage losses which had been cited as a drawback to the adoption of

this technology. A farmer who invested in the lining of their 100m³ capacity water pan with UV resistant plastic material and installed the drip system had a net income of Ksh. 74,800 against Ksh. 17,900 for those without the investment. The return to investment (lining and drip irrigation system) indicated that the farmer could recover the investment cost within one season. Therefore; on-farm RW storage system was a viable investment in Matanya. The up-scaling of RWH technologies should therefore be promoted and supported through various interventions in Laikipia Central District as they were found to significantly improve agricultural productivity.

CHAPTER ONE: INTRODUCTION

1.1 Background

Agriculture continues to be a fundamental instrument for sustainable development, poverty reduction and enhanced food security in developing countries. Agricultural productivity growth is also vital for stimulating growth in other sectors of the economy (World Bank, 2007). Currently, agricultural productivity growth in Sub-Sahara Africa (SSA) lags behind that of other regions in the world, and is well below that required to achieve food security and poverty reduction goals (Tegemeo, 2008). The first Millennium Development Goal (MDG 1) is to eradicate extreme poverty and hunger; this goal is the backbone for achieving the other seven MDGs (World Bank, 2007). Today, there is a global outcry over food insecurity. There is evidence from Food and Agricultural Organization (FAO) that 850 million people in the world are affected by food insecurity, of whom 820 million live in the developing countries (Ngaira, 2009).

The agricultural sector in Sub-Saharan Africa is predicted to be especially vulnerable to climate change because this region already endures high heat and low precipitation, provides the livelihoods of large segments of the population, and relies on relatively basic technologies, which limit its capacity to adapt (CEEPA, 2006). Rain-fed systems are essential for improved food security because of the high degree of reliance of the food insecure population on these systems (Molden, 2007). Increasing the crop water productivity in smallholder farming is required since the productivity is often low but has the largest potential to be enhanced (Molden, 2007).

Agriculture accounts for about 70% for total global water use with the abstraction being highest in the least developed regions of the world (Inocencio et al., 2003). Sub-Saharan Africa faces severe food security problems since its economies cannot afford expensive investments in water infrastructure like dams. With increase in both rural and urban populations, the allocation of water for agriculture will have to give way to high value urban (industrial and domestic) and domestic use in the rural areas. This will aggravate the problem of food insecurity in most countries in Sub-Saharan Africa (Inocencio et al.,

2003). The situation is worse in the semi-arid areas where the population is increasing rapidly with decreasing land sizes.

In Sub-Saharan Africa rainfall is highly erratic, and normally falls as intense storms, with very high intensity and spatial and temporal variability. Severe crop reductions caused by dry spells occur one to two out of five years, while total crop failures caused by annual droughts occur once in every 10 years in semi-arid SSA (Rockström, 2000). This means that the poor distribution of rainfall rather than absolute water scarcity, more often than not leads to crop failure due to low cumulative annual rainfall. Unfortunately, most dry spells occur during critical crop growth stages and hence the need of dry spells mitigation by improving water productivity in SSA.

In Kenya, growth of the national economy is highly correlated to growth and development in agriculture. The Government long-term development blueprint for the country, Kenya Vision 2030 has identified agriculture as one of the key sectors to deliver the 10 per cent annual economic growth rate envisaged under the economic pillar (Republic of Kenya, 2007). To achieve this growth, it is critical to transform smallholder agriculture from subsistence to an innovative, commercially oriented and modern agricultural sector. This transformation will be accomplished through, among others, the development of more irrigable areas in arid and semi-arid lands for both crops and livestock (Republic of Kenya, 2008).

Two-thirds of Kenya's total land area has low, unreliable and poorly distributed rainfall with high evaporation rates leading to unreliable agricultural production. Despite the environmental limitation, the marginal areas are experiencing the greatest population increase as land for agriculture becomes scarce in the wetter highlands (Orodho, 1998). Consequently food production has lagged behind population growth in these areas to the extent that majority of smallholder farmers cannot adequately provide for their livelihoods (Republic of Kenya, 2010).

The Ministry of Agriculture has identified long term interventions as a solution to chronic food insecurity in the ASALS in its Strategy to Revitalize Agriculture (SRA) (Kiome, 2009). Among the interventions is rainwater harvesting for crop production to address food insecurity (Kiome, 2009).

1.2 Problem statement

Small holder farmers in Laikipia Central District are faced with a challenge of small farm sizes in a semi-arid environment. Most of the newly settled areas are only marginally suitable for rain-fed agriculture and the risk of crop failure is very high. The food requirements of the ever increasing population cannot be met by mixed farming alone. Out of the entire population in Matanya Location-66%, 42%, 65%, 40% and 40% had been on relief food during the years 2005, 2008, 2009, 2010 and 2011 respectively (Caritas Nyeri, 2011).

Increased dry season abstraction of rivers by farmers upstream was already causing periodic water shortages in the lower parts where Laikipia Central District lies. Water abstraction assessment revealed that about 62% of the dry season flow and 43% of the wet season flow was abstracted from Naro Moru River before its confluence with Ewaso Ng'iro River (Kiteme et al., 2007). This shows heavy utilization of river flows through abstractions to support human, livestock and irrigation. Though the river is perennial, over-abstraction, of which more than 70% was illegal (Aeschbacher et al., 2005; Gichuki et al., 1998), leads to drying up of the lower reach during the driest months of February and March, and under extreme conditions from July-September. This has been a source of conflict between smallholder farmers and pastoralists (Liniger et al., 2005) in this region. The area has been experiencing the impacts of climate change related to recurring droughts leading to environmental degradation; declining water resources; food insecurity; and diminishing sources of household income.

1.2.1 Justification

Provision of water is in most cases accompanied by increased level of crop production. In Zimbabwe Chimvi District, the adoption of the rain water harvesting (RWH) technologies enabled the farmers to grow at least two crops on a rotational basis in one calendar year, implying that the farmers were intensively utilizing their land (Mutekwa and Kusangaya, 2006). Increased crop productivity may lead to improved household food security and incomes. More often, provision of water encourages the shift from subsistence to commercial farming. A case study of Mwala District, Kenya indicated that, with RWH, farmers had diversified crop production to include horticultural cash crops and households earned US\$735(per ha) from cash crop compared with US\$146 normally earned from rain fed maize (RELMA-in-ICRAF, 2004).

Ngigi et al. (2005) reported that a return to investment analysis for a farmer in Laikipia who had invested in a 50 m³ farm pond and a low-head drip irrigation system for a 0.2 ha plot of maize compared with a conventional system without rainwater harvesting and management (RHM) system had a payback period of about 4 seasons (two years).

Some smallholder farmers in Laikipia were currently investing in rainwater (RW) storage systems for production of high value vegetable crops such as tomatoes and snowpeas. However, data on the returns to this investment was currently unavailable.

The study thus focused on the evaluation of smallholder farms in Laikipia Central District that had adopted RW storage systems and were in production of high value vegetable crops using furrow and drip irrigation. The study was aimed at establishing the role of rain water harvesting on improvement of household food security and income status of the farmers in the study area.

1.3 Study objectives

1.3.1 Overall objective

The overall objective was to document rainwater harvesting practices, cropping systems and crop productivity by smallholder farmers in Laikipia Central District.

1.3.2 Specific objectives

- a) To identify the current rain water harvesting practices used in the area.
- b) To document the type of crops grown and cropping systems among the smallholder farmers using rain water harvesting.
- c) To assess crop productivity between households with and those without rainwater harvesting systems.

1.3.3 Research questions

- a) What rainwater harvesting practices are being used in the area?
- b) What are the main crops grown and cropping systems adopted in the area using rainwater harvesting systems?
- c) Is there a difference in crop productivity between households with and without water harvesting systems?

CHAPTER TWO: LITERATURE REVIEW

2.1 Small-scale farming in Kenya

The main feature of Kenya's agriculture is domination by 3.5 million smallholder farmers. Production is carried out on farms averaging 0.2–3 ha. Over half of the smallholder farms are less than 1.5 hectares while about one-third of the farms nationwide are less than 1.0 hectares in size (Tegemeo, 2011). Though most of Kenya's smallholder farmers reside in increasingly densely populated high rainfall areas, land pressures has forced them to migrate to the marginal areas. In Laikipia the farm sizes vary between 0.4 and 9 ha, with an average size of 2 ha (Lewis and Ndung'u, 2006).

The small-scale production accounts for 75% of total agricultural production and 70% of marketed agricultural output. On average, small-scale farmers produce over 70% of maize, and 70% of beef and related products. However, about half of Kenya's total agricultural output is non-marketed subsistence production (Republic of Kenya, 2004). Limited availability of productive land is a major constraint to increased agricultural production due to land fragmentation and decreasing land-size per household. Survey by Tegemeo (2008) showed that household land holdings in marginal rain shadow agro-regional zone registered a decline of 15% from 6.1 acres in 1997 to 4.4 acres in 2007.

Nationally, the average cropped land per household declined from 3.5 acres to 3.4 acres with the marginal rain shadow agro-regional zone registering a decline from 6.1 acres to 4.4 acres in 1997 to 3.4 acres in 2007 (Tegemeo, 2008). The general decline in sizes of landholding reflected the effects of increased population pressures and sub-division in most areas of rural Kenya. Productivity would thus have to depend on yield gains made by wide-spread use of productivity-enhancing technologies.

Among these technologies are high yielding varieties supplemented by other productivity enhancing inputs, mainly fertilizer, to exploit their full productivity potential (Tegemeo, 2008) and increasing the water productivity. Nationally, there was an increase in the proportion of farmers combining fertilizer and high yielding varieties (HYV) for major

food crops from 51% in 1997 to 61% in 2007. Farmers' attempt to raise soil fertility was reflected by the proportion of households using organic fertilizer (farmyard and compost manure) which increased from 44% in 2000 to 50% in 2007 (Tegemeo, 2008). However, in semi-arid regions the use of the combined fertilizer/HYV package declined from 14% in 2000 to 11% in 2007 and that of organic fertilizers from 76% in 2000 to 68% in 2007 (Republic of Kenya, 2008). The major reason for this was that since semi-arid regions were only marginally suitable for crop production, the returns to fertilizer use was low and high risk of crop failure due to insufficient rainfall.

Important strategies towards achieving increased agricultural productivity include availability of working capital to the farmers to acquire adequate productivity enhancing inputs. Kibaara, (2006) demonstrated that farmers who accessed agricultural credit recorded higher level of maize productivity than those that did not. The other strategy was access to irrigation water especially for vegetable crops to help stabilize incomes for farmers in low potential areas (Tegemeo, 2008). Since HYV seed tends to go hand-in-hand with recommended fertilizer application rates and with less stressful moisture conditions, water availability is an important consideration in raising productivity for farmers in low potential areas.

2.2 Cropping systems

Most of the small-scale farmers in Laikipia practice subsistence mixed farming with rain-fed crop cultivation and livestock keeping. Crops grown here include maize, beans, Irish potatoes and improved pasture. Where river, canal or stored water was available, horticultural crops such as cabbages, tomatoes, onions and carrots are grown under irrigation (MoA, 2008-2011).

The increased small scale farm settlements and the booming horticulture sector upstream have put increasing pressure on river water resulting to competition and conflicts among the different user groups. It has also grossly contracted the area where water was reliably available during dry seasons even to the extent of the drying of irrigation canals (Liniger et al., 2005). In Kenya, intercropping maize with other crops is common among the smallholder maize farmers (Tegemeo, 2008). In Laikipia, intercropping maize with beans

or Irish potatoes is the dominant cropping system among the small-scale farmers. However, horticultural crops grown off-season under irrigation from RWH are in pure stands (Ngigi et al., 2005).

In ASAL, periods of severe water stress are common and often coincide with the most sensitive stages of growth. Barron et al. (2003) showed that in any year, there was a 70% probability of a dry spell exceeding 10 days during flowering for maize in semi-arid Machakos (Kenya) and Same (Tanzania) districts. Crop production is difficult in this area; due to high evapo-transpiration losses and sparse rainfall (Gichuki et al., 1998). Maize faces the greatest risk owing to its lengthy growing period and its sensitivity to unevenly distributed rainfall (Barron et al., 2003).

Despite the risk, Tegemeo (2008) reported that there had been only a small decline in the proportion of land allocated for maize in the marginal areas from 77.2% in 1997 to 74.9% in 2007. To reduce the production risks, farmers plant crops with different water demands during their growth period. Beans are not drought resistant but they have a shorter flowering and yield formation phase and are less sensitive to moisture stress compared to maize during this phase. Irish potatoes have better tolerance to moisture stress than maize or beans. Their critical phase is the tuber formation which comes 20-30 days after planting. On average, for beans and Irish potatoes, two out of three of all years allowed a constraint free yield in the long rains growing period (Situma, 1997).

Land use changes, especially intensification of rainfed agriculture, are driven by the need to improve agricultural production and livelihoods. One such land use change is adoption of RHM systems, which aim to enhance soil moisture and runoff storage for food production (Macharia et al., 2009).

2.3 Rainwater harvesting

2.3.1 Rainfed agriculture and water stress

The world is facing multiple challenges in the 21st century and these are poverty, food security, scarcity of water and, complex challenges emerging due to global warming and climate change (Wani et al., 2003).

Most of the 852 million poor people in the world live in the developing countries of Asia and Africa, more so in marginal areas. Though rainfed agriculture constitutes 80% of global agriculture and plays a crucial role in achieving food security, increasing water scarcity and climate change threaten to affect rainfed areas and their peoples owing to their vulnerability to drought during the crop-growing season (Molden, 2007). However, in dry regions, Rockstrom et al. (2007) reported that yields were constrained by long dry seasons and strong weather variability rather than insufficiency of total annual rainfall. During the rainy season, the combined effect of the high rates of evaporation and runoffs led to shortage and high variability of soil moisture which limited plant growth (Hatibu *et al.*, 2006).

The importance of rainfed sources of food weighs heavily on women, given that approximately 70% of the world's poor were women (WHO, 2000). Agriculture plays a key role for economic development and poverty reduction, with evidence indicating that every 1% increase in agricultural yields translates to a 0.6–1.2% decrease in the percentage of absolute poor (Thirtle et al., 2002).

The importance of rainfed agriculture varies regionally but it is the major source of food for poor communities in developing countries. In Sub-Saharan Africa (SSA) more than 95% of the farmed land is rainfed, while the corresponding figure for Latin America is almost 90%, for South Asia about 60%, for East Asia 65% and for the Near East and North Africa 75% (FAO, 2002).

Rainfed agriculture is a risky business due to high spatial and temporal variability of rainfall. Rainfall is concentrated in short rainy seasons (approximately 3–5 months), with few intensive rainfall events, which were unreliable in temporal distribution, manifested

by high deviations from the mean rainfall (Coefficient of Variation = 40% in semi-arid regions) (Wani et al., 2004).

In Kenya, agriculture is mainly rainfed and is possible in about 16 per cent of the landmass which is of high and medium agricultural potential with adequate and reliable rainfall. Of this potentially arable land, cropland occupies 31 per cent. The rest of the country (84%) is arid or semi-arid and is not suitable for rain-fed farming due to low and erratic rainfall (Republic of Kenya, 2010).

2.3.2 Water harvesting for improved rainfed agriculture

The Kenya Meteorological Department (KMD) analysis of the impacts of climate change in Kenya over the last 50 years reported a change in regard to rainfall patterns. Frequency analysis of 16 years (1987-2002) by Ngigi et al. (2005) daily rainfall and evaporation data for Matanya rainfall station in Laikipia indicated that the probability of occurrence of seasonal rainfall lower than the long term average is 60% for both long and short rainfall seasons. One promising technology for rural land use systems is harvesting of rainfall that otherwise causes floods and flash floods that lead to run-off, causing soil erosion, destruction of infrastructure and pollution of existing water resources (Ngaira, 2009). The management of this rainwater will help to mitigate the effects of intra-and inter seasonal dry spells that are common in the semi-arid area. Rain-water harvesting is broadly classified into two groups:

1. Run-off collected from a micro-catchment and stored for consumptive use in the plant root zone e.g. ridging, terracing
2. Run-off harvesting from a catchment using channels or diversion systems and stored in a surface reservoir (Rockstrom, 2000).

The potential contribution of rainwater harvesting in the semi-arid areas include; reducing the pressure to invest in high cost infrastructure development like dams and run-of-the-river diversion schemes, cheap technology that is available to the poor farmers like the manual pumps and environmental benefits with the reduced pressure on groundwater

resources exploitation like drilling of boreholes. In addition, rain-water harvesting, conservation tillage and precision agriculture can increase the effective rainfall use for crop production (Inocencio et al, 2003).

One of the promising breakthroughs for upgrading rainfed agriculture in the semi-arid lands remains on how efficiently small scale farmers can utilize practices such as RWH. RWH for agriculture can be viable in areas with annual rainfall of as low as 300 mm (Ngigi, 2003). Besides increased yields, Ngigi et al. (2005) reports that rainwater harvesting and management (RHM) is also aimed at stabilizing variations in crop yields and ensuring food security. Results from a study in Tanzania, Mutabazi et al. (2004) indicates that external catchment based rainwater harvesting assured significantly higher and stable yields and economic returns compared to in-situ and rainfed systems, particularly during below-average seasons. They concluded that an external catchment based rainwater harvesting had eminent potential of mitigating rainfall-related crop production risks in the dryland tropics.

Other benefits of rain-water harvesting are that it makes the water available at the point of consumption and reduces the need to pump or haul it over long distances thus saves on time and human labour. The experience of rainwater harvesting activities indicates that they could be used as a catalyst for development to alleviate poverty and to promote socio-economic well-being of rural people (Mbugua and Nissen-Petersen, 1995).

The role of small scale water harvesting systems in Sub-Saharan Africa is however yet to be realized. This is despite the potential it has of addressing spatial and temporal water scarcity for domestic, crop production, livestock development, environmental management and overall water resources management (Ngigi, 2003).

Large scale irrigation has been seen to be the solution to all food deficit and water shortages, but the considerable problems, both technical and social, has shown that most of the large scale irrigation schemes can not realize their full potential (Amha, 2006). Rosegrant et al. (2002) also reports that though cereal yield under irrigated farming is

much higher (1.71 ton/ha) than cereal yield under rainfed (0.83 ton/ha) in SSA, the overall production from rainfed agriculture is 93% of the total production.

Because of the risk associated with climate variability, smallholder farmers are generally and rationally keen to start by reducing risk of crop failure due to dry spells and drought before they consider investments in soil fertility, improved crop varieties and other yield-enhancing inputs (Hilhost and Muchena, 2000).

Soil and water conservation or in-situ water harvesting systems form the logical entry point for improved water management in rainfed agriculture (Hilhost and Muchena, 2000). Since in-situ rainwater management strategies are often relatively cheap and can be applied literally on any piece of land, they should be optimized on any field before supply of water from external sources is considered (Hilhost and Muchena, 2000). The rainwater harvesting technologies that have been tested and found suitable for increasing crop productivity are those that retain rainwater in-situ in the farms for crops (tied and open ridges) or those that allow rainwater to be retained on open furrows for longer duration as the water infiltrates the soil. Alternatively, soil management techniques that favour prolonged rainwater infiltration and retention thus raise the overall soil moisture retention and soil water holding capacity (Itabari and Wamuongo, 2003).

However, a number of RWH technologies are integrated or combined by land users. For example, fields under conservation tillage in Laikipia District also incorporate runoff spreading from small external catchments such as road/footpath drainage and adjacent fields (Kihara, 2002). In-situ water conservation is also combined with runoff farming on farms with terraces, in which the terrace channel (mainly *fanya juu* and contour ridges/bunds) collects and stores run-off from small external catchments while the cropland between the channels harvest and conserve direct rainfall (Kihara, 2002; Muni, 2002).

Run-off harvesting from a catchment using channels or diversion systems and storing it in a surface reservoir-water pans/ponds (Rockstrom, 2000) have shown that the yields and reliability of agricultural production can be significantly improved with water harvesting. In this system, surface runoff from small catchments or adjacent road runoff is collected and stored in manually and/or mechanically dug farm ponds. Though this

technique requires relatively high investment costs compared to in situ systems. Evaluation of RWH in a surface reservoir in four Great Horn of Africa (GHA) countries (Ethiopia, Kenya, Tanzania and Uganda) revealed that, it was slowly being adopted with high degree of success (Kiggundu, 2002).

According to Macharia et al. (2009), run-off harvesting from a catchment using channels or diversion systems and storing it in surface reservoir-water pans/ponds was gaining popularity in Matanya. Farmers have dug individual waterpans to harvest and store runoff water that they use for farming. Runoff is collected from grazing land, uncultivated land, cultivated land and road drainage and directed into small manually constructed reservoirs (50–200 m³). Impact of rainwater harvesting as shown in a case study of Mwala District, Kenya indicates that harvesting runoff water for supplemental irrigation was a risk-averting strategy, pre-empting situations where crops had to depend on rainfall that is highly variable both in distribution and amounts (RELMA-in-ICRAF, 2004). With rainwater harvesting into underground tanks, farmers have diversified to include horticultural cash crops and the keeping of dairy animals. This has contributed to food security, better nutrition and higher family income (RELMA-in-ICRAF, 2004).

Studies of supplemental irrigation of maize and cabbage using farm ponds in Kenya, (Ngigi et al., 2000) found out that, improved farm ponds provides one of the feasible options of reducing the impacts of water deficit that affect agricultural productivity in semi-arid environments in SSA.

Initiatives arising from a multi-stakeholder approach focusing on addressing the challenges of sustainable and equitable water use at basin and common resource level were initiated in the Ewaso Ng'iro North Basin (Kiteme et al., 2008). Among the most successful initiatives were Water User Associations (WUAs). The work of WUAs had extended beyond conflict resolution and included rainwater harvesting and improved river water storage; and catchment protection through afforestation, among other measures (Kiteme et al., 2008).

2.3.3 Challenges in adoption of RWH

The use of on-farm storage reservoirs faces evaporation and seepage losses and silting (Thome, 2005). It is important to minimize the adverse effects of these problems in the design of a surface-water storage facility. Silting may be minimized by arresting the silt and sand on the catchment area itself, mainly through controlling catchment erosion but also by installing silt-traps (Thome, 2005). The author continues to state that other than minimizing the water surface area, there was no cost effective way of eliminating evaporation losses from open water bodies.

In Laikipia, loss of water through seepage has been identified as a major drawback (Kihara, 2002). The water losses were found to account on average to 30–50% of the stored water and worse still, in farms with sandy soils, most of the water was lost almost immediately after the rains (Ngigi et al., 2005). Thus despite the positive impact realized by this technology, its widespread adoption could be hampered if simple seepage control measures were not devised.

Concrete sealing seems to work well in Ng'arua Division of Laikipia district, but the cost may be beyond the reach of many farmers. Farmers were still experimenting with various seepage control methods, among them, plastic lining (Kihara, 2002). The results from plastic lining suggest that there are benefits associated with controlling water losses and improving irrigation water management (Ngigi et al., 2005). The benefits include more water for the crops especially to meet water demands during the dry seasons, which sometimes coincide with critical growth stages.

Another challenge is that the RHM systems, to some extent depend on rainfall distribution. During extreme drought years, very little can be done to bridge a dry spell occurring during the vegetative crop growth stage if no runoff producing events occur during early growth stages (Rockström, 2000).

Ngigi et al. (2005) reported that a situation may arise where increased production can reduce market prices and hence lower incomes, which may then lead to a decline in adoption rate of RWH technologies.

2.3.4 Maximizing benefits of supplemental irrigation

In SSA, water is a scarce resource and the amount of water available for supplemental irrigation (SI) is generally limited. In such situations, an efficient application of water was very critical as it could contribute significantly to reducing water losses and increasing water use efficiency (Fox and Rockstrom, 2003). Broadly, the methods used for application of irrigation water can be divided into two types, namely surface irrigation systems (border, basin and furrow) and pressurized irrigation systems (sprinkler and drip) (Rockström et al., 2001). The former is not very efficient and water losses through seepage and evaporation are very high. The drip irrigation is the most efficient system for the application of supplemental irrigation water. It is most effective in reducing the water losses and increasing irrigation efficiency. Cheap drip kits save water and labour, and were increasingly adopted among farmers (Ngigi et al., 2000).

Compared with other irrigation systems (sprinkler and furrow irrigation), the drip systems provide the most uniform and adequate moisture to the plants. The drip system is also the most efficient in terms of water application efficiency (90-98%), followed by sprinkler (80-95%) and furrow (40-60%) (Sharma and Sharma, 2007). It is also the most economical system for high-value crops such as horticultural crops.

Although drip systems are very efficient, they do have some drawbacks. A reliable, continuous water supply with good infiltration was necessary to run a drip system (Oweis and Hachum, 2003; Rockström et al., 2007). Rotating crops with different spacing requirements could be problematic after a drip system was installed and could not be practical for closely spaced annual crops. Thus, its use was very limited for most of the commonly grown annual crops by resource poor farmers in the SSA (Oweis and Hachum, 2003; Rockström et al., 2007).

Supplemental irrigation alone, although it alleviated moisture stress, cannot ensure highest performance of the rainfed agricultural system. It has to be combined with other good farm management practices (Rockström et al., 2001). In experiments done in Kenya (Machakos District) and Burkina Faso (Ouagouya), the results show that the highest

improvement in yield and water use efficiency was achieved by combining supplemental irrigation and fertilizer application (Rockström et al., 2001).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of study area

Matanya Location is one of the six locations in Laikipia Central District. It is located to the south west of Nanyuki town at longitude $36^{\circ} 57' 12''$ East and latitude $00^{\circ} 03' 12''$ South (Figure 3.1). It is at an altitude of 1840 m above sea level and it lies in the rain shadow of the Mt. Kenya and Aberdare Ranges. It covers an area of 121 square kilometers and has a population of 14,848 in 4,095 households (KNBS, 2009). The ecology of the area in respect to crop production is determined on one hand by its leeward position behind Mt. Kenya in regard to the moisture carrying eastern winds, and on the other hand by its altitude which reduces the average annual temperature to 18°C (Jaetzold and Schmidt, 2006).

The annual rainfall received in Matanya area ranges between 650 and 750 mm p.a., most of which is distributed in two rainy seasons: Long rains (March to June) and Short rains (October to January) (Appendix 2). The average rate of potential evaporation is 5.8mm day^{-1} and 4.7 mm day^{-1} during the dry and wet seasons respectively (Liniger et al., 1998) (Appendix 4). The rains are locally and geographically influenced by Mt. Kenya and the Aberdare Ranges (Jaetzold and Schmidt, 2006).

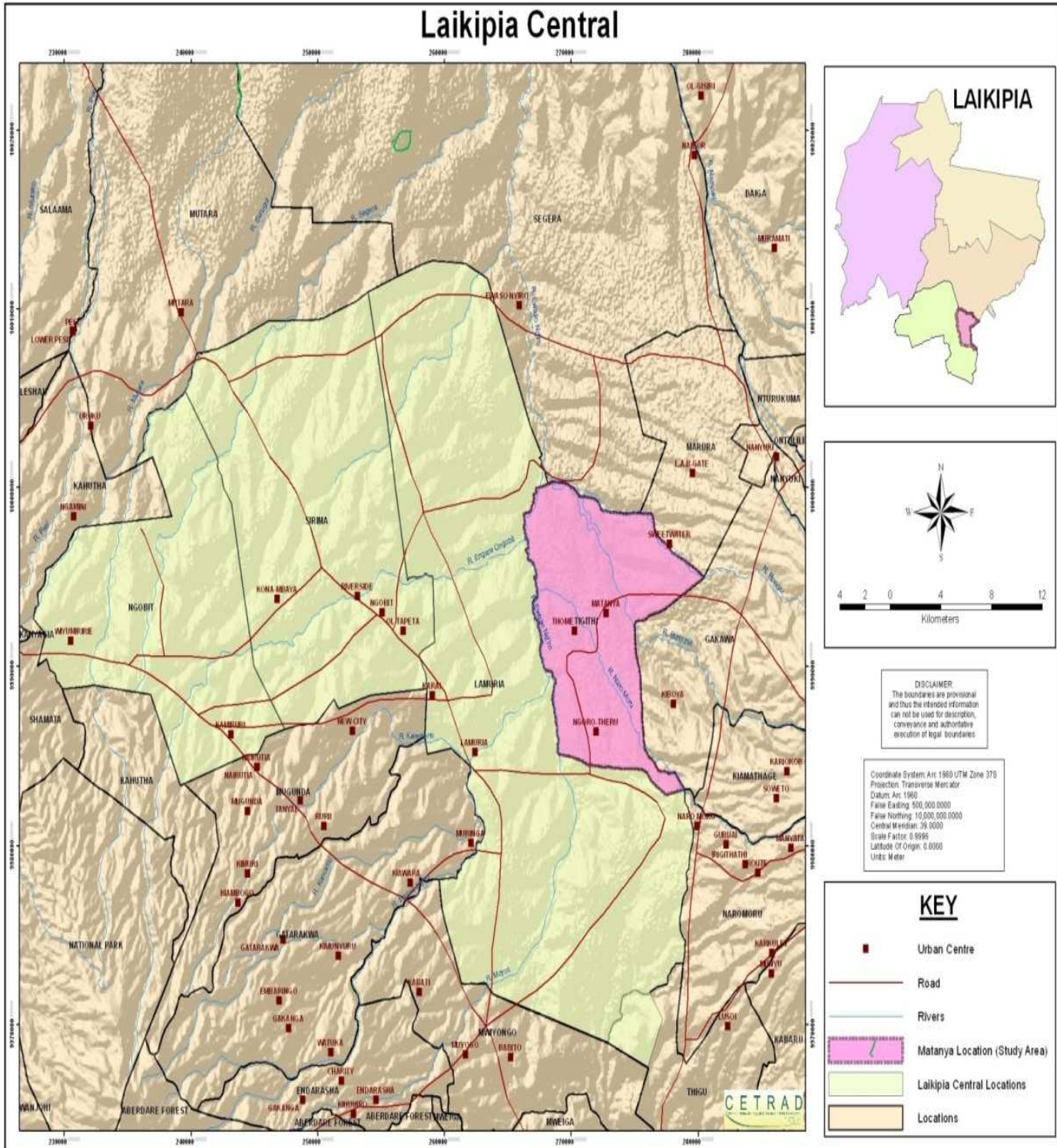


Figure 3.1 Location of study area (Source: CETRAD, 2011)

The short rains are higher and more reliable than the long rains. The lengths of the long and short rainfall seasons are 55-90 days and 62-85 days respectively. This means that the lengths of the rainy seasons are shorter than growing periods for most crops grown in the study area: 125 and 75 days respectively for maize and beans/irish potatoes (Situma, 1997). This coupled with occurrence of frequent intra-seasonal dry spells affected overall agricultural production (Ngigi et al., 2005). The mean annual temperatures range between 16°C and 20°C. The soils in this plateau are very deep (120-180 cm) *vetro* Luvic and *luvic* Phaeozem of imperfect to moderate drainage.

The farm sizes are small ranging from one to two hectares per household. Mixed farming is the major land use where crops and livestock were raised (Lewis and Ndung'u, 2006). Under rainfed agriculture, intercropping systems are predominant and they include intercropping maize with beans, and maize with Irish potatoes. While cabbages, tomatoes, kales, spinach garden peas and onions are grown under irrigation. Only about 10% of farmers used farm yard manure and inorganic fertilizers in the area (Ministry of Agriculture, 2008). Amongst the local population, food shortages were common and malnutrition was on the increase because of low food production, a consequence of recent poor rainfall and declining soil fertility (Ministry of Agriculture, 2008-2011).

Matanya Location was selected for this study because the area, besides being prone to droughts, was one of the areas in Laikipia District in which RWH technologies (mulching, conservation agriculture) and drought tolerant crops were introduced and promoted by a number of organizations including, Laikipia Research Programme, Ministry of Agriculture and Ol Pejeta Conservancy (Ministry of Agriculture, 2008-2011; Schafer, 2008).

3.2 Study approach

3.2.1 Survey

A survey was conducted between 10th October to 23rd December 2011 cropping season using a pre-tested questionnaire with open-ended and closed questions. The survey included interviews of 100 farmers. Selection of respondents was based on the population distribution within the four identified blocks.

This was followed by another survey targeting the farms that had waterpans to determine their effectiveness in terms of retaining water and their use during the January to March 2012 dry period in crop production and in particular vegetables.

According to Lewis and Ndung'u (2006), 75% of households in Matanya were small holder farmers. Thus out of the total 4,095 households, 3,072 were smallholder farmers. Therefore, the sample size was determined according to Fisher et al., (1991).

$$n = (z^2 pq) / d^2 \dots\dots\dots \text{Equation 1}$$

Where, n is the desired sample size, z is the standard normal deviation, usually set at 1.96 which corresponds to 95 % confidence interval.

p is the proportion of the population estimated to have a particular characteristic e.g. proportion of households practicing rainwater harvesting (0.9). Small-scale farmers in Matanya location being mixed farmers; will be in one way or another be practicing rainwater harvesting for production (crop and livestock) or even for domestic use.

q = 1-p, proportion of households not practicing rain water harvesting (0.1)

d = the degree of accuracy usually set at 0.05

$$n = [1.96^2(0.9)(0.1)] / 0.05^2$$

n=138.3 which is approximately 140.

The study used a sample of 100 farmers obtained through stratification of the population so as to reduce variability and increase precision (Ric, 1996).

The study population was stratified into two sub-populations i.e. with and without access to canal water. The number of farmers served by the canal was obtained from the water management committee while for those not served by the canal was obtained from the Focal Area Development Committee (FADC) under NALEP. The population data was later cross checked with the local administration from the 2008 pre-census data for various villages (KNBS, 2009).

The households interviewed were allocated to the two sub-populations through purposive multistage design (using the Probability Proportion to Size sampling design) where the sub-population with more people got a higher proportion of the sample size. Those not served by the canal were then proportionately apportioned among the three FADC blocks namely Thome, Kabanga and Matanya (Table 3.1).

The sample size per block was allocated proportionately to their respective populations. The household study interval was determined by the ratio of sample size to the total number of farm holdings within a block.

Table 3.1 Target farm holdings in the four study blocks

Block	Number of households	Number of farm holdings	Sample size	Percentage of total farm holdings	Interview interval
Tigithi	1,169	877	30	3.4	29
Thome	1,011	758	24	3.2	32
Matanya	965	724	23	3.2	32
Kabanga	950	713	23	3.2	31
Total	4,095	3,072	100	-	-

The type of data collected was on household characteristics, farm characteristics, farm enterprises, soil and water conservation technologies, water availability, extension services availability, type of crops and their level of production, application of inputs, use of farm implements, crop prices and marketing, farm income and expenditure (Appendix 1).

The primary data was complemented with information gathered through visual observations and focused group discussions with the two committees (FADC and Tigithi canal management committee) and key informants (Divisional Agricultural Officer, area Sub-Chief, Secretary of Naru Moru River Users Association and Extension Officer Ol Pejeta Conservancy Project).

3.2.2 Gross margin analysis

To determine the economic productivity of adopting RWH, with its related investments, a simple gross margin (G.M.) analysis was done for maize, tomatoes and cabbages. Maize was chosen as it was the major food crop and was being grown by 90% of the farmers under RWH. For the commercial crops, tomatoes and cabbages were the major crops (46% and 37% of the farmers respectively). The prevailing market prices for farm produce, inputs and labour were used in the G.M. analysis. Gross margin is equal to gross output (G.O.) minus variable costs (V.O.).

The acreage of cropped area under irrigation was based on the storage capacity of the existing waterpans and water application method. A productivity comparison was done to show the benefits associated with investing in the lining of the water pan and drip system. A return to investment was used as an analytical method of guiding a farmer, in what he/she stood to gain or lose by deciding either to adopt or not to adopt the rain water management system.

3.3 Data analysis

Data was analyzed using the Statistical Package for Social Scientists (SPSS) Version 15.0 for Windows (Miller et al., 2006). Means, standard deviation, chi-square value, coefficient of variance, graphs, percentages and frequency tables were used to explain the various descriptive aspects of the study results.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Rainwater harvesting technologies

Due to the rainfall shortage for crop production, farmers had developed various coping strategies (Table 4.1).

Table 4.1 Coping strategies adopted by farmers against rainfall shortage

Coping strategy	Frequency	Percentage
Rain water harvesting	44	31
Growing drought tolerant crops	36	25
Switching to livestock production	27	19
Change of planting dates	21	15
Use of river water for irrigation	11	8
Crop insurance	2	1
None	2	1
Total	143	100

Rain water harvesting for crop production had been identified by the farmers (31%) as a viable option. The rainwater harvesting practices used by the farmers were those that encompassed: (1) in-field soil and water management and (2) surface storage i.e. water pans/ponds. Under the in-field soil and water management, the techniques used were *fanya juu*, tied ridges/furrows, mulching, large pits (*tumbukiza*), small pits (*mategu*), and conservation tillage (Figure 4.1). Overall, the RWH technologies adopted by farmers in the study area were small-scale in nature making them well suited to farm operations by individual households, which were the primary units of agricultural production in the rural areas.

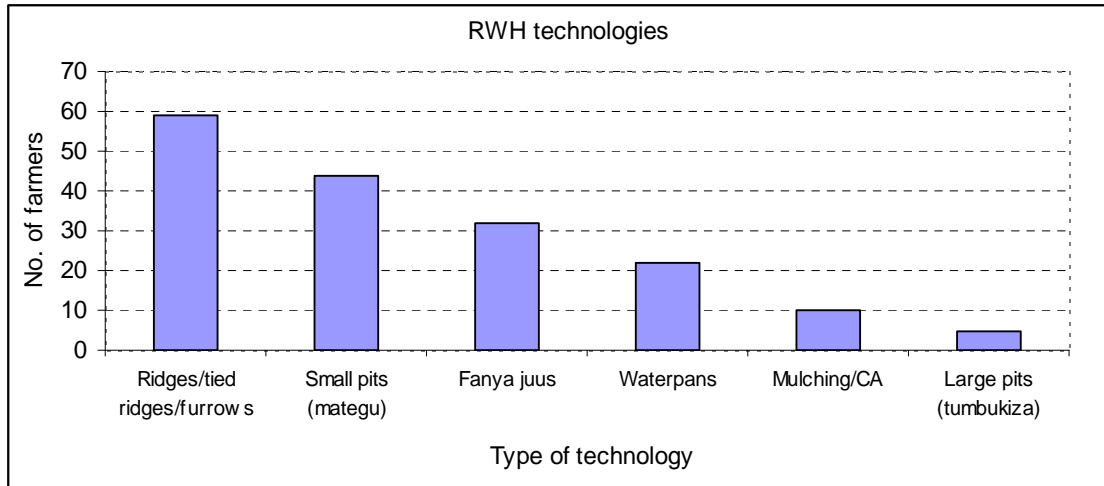


Figure 4.1 Rainwater harvesting technologies in Matanya

A similar study in Zimbabwe (Mutekwa and Kusangaya, 2006) showed that farmers adopted a wide spectrum of RWH techniques, with the most common techniques being infiltration pits (61%), *fanya juus* (34%), tied ridges (27%), macro-catchments (10%) and graded contours (7%). Infiltration pits were a popular choice as they seemed to retain more moisture in the soil and allowed the growing of a variety of crops. The technologies that encompassed in field soil and water management were most popular with the farmers as they were very compatible with the farmers cropping systems. These technologies were also implemented using the common hand tools that farmers used in crop husbandry practices right from land preparation, planting, weeding and earthling-up where applicable. This was in agreement with Hilhost and Muchena, (2000) who reported that since in-situ rainwater management strategies were often relatively cheap and could be applied literally on any piece of land, they were preferred before supply of water from external sources were considered.

The manure application supplemented these technologies as it did improve the soil structure and impacted positively on water infiltration and water holding capacity. This ensured that much of the rainwater arising from the heavy poorly distributed storms that were characteristic of the ASAL areas were retained for use by the crop. Crop productivity was also increased through soil management techniques that favored

prolonged rainwater infiltration and retention thus raised the overall soil moisture retention and soil water holding capacity (Itabari and Wamuongo, 2003).

The furrows/ridges/tied ridges were very common with the growing of virtually all the crops that the farmers grew as they helped harvest and retain the water around the crop. Ridging was also an agronomic practice in irish potatoes production as it ensured more lower stem nodes were covered with soil for maximum tuber production.

Itabari and Wamuongo (2003), concluded that the rainwater harvesting technologies that had been tested and found suitable for increasing crop (tied and open ridges) productivity were those that retained rainwater in-situ in the farms for crops or those that allowed rainwater to be retained. However, during periods of continuous heavy rains as was the case during the 2011 short rains in Matanya, excess water caused waterlogging leading to tuber rot and poor yields in irish potatoes. To eliminate this danger, Mmbanga and Lyamchai (2001), recommended crest and side seed placement.

The small pits (*mategu*) were common in maize production as apart from ensuring that water was harvested and retained around each plant, it was easily incorporated in hand maize planting using fork/plain *jembes*. Incase where a dry spell occurred immediately after crop establishment, or incase an early rain season cessation, the crop was not adversely affected unlike those not in pits or in ridges/furrows. Mati (2005) observed that the required labour for digging the holes was low and that crops usually survived even during periods of severe rainfall deficits and yields had been noted to be triple.

Fanya-juu terraces were a common physical soil erosion control measure. The structure had for a long time been promoted by the Ministry of Agriculture as a soil erosion control measure and was thus a common feature in high rainfall areas where the farmers migrated from. The stabilized embankment also blocked the water from running down slope giving it time to infiltrate into the ground. The farmers mostly used napier grass as the stabilizing vegetation and it therefore benefited from the retained moisture.

Run-off retention furrows harvested run-off from external catchments like uncultivated plots, roads and footpaths. The run-off was directed to the field through furrows and once

in the field it was allowed to spread into the cropped area or infiltrated slowly into the soil (Kihara, 2002). However, during periods of heavy and/or continuous rains there was a danger of flooding and waterlogging in the fields as the structures had no regulatory mechanisms.

It was very common to find the farmers using a combination of these RWH technologies on their farms and even on the same crop(s). Kihara (2002) observed that in Laikipia, in-situ water conservation was also combined with runoff farming on farms with terraces, in which the terrace channel (mainly *fanya juu* and contour ridges/bunds) collected and stored run-off from small external catchments while the cropland between the channels harvested and conserved direct rainfall. In some instances, farmers adopted more than one RWH technique so that they were able to grow more crop varieties (Mutekwa and Kusangaya, 2006).

4.1.1 Characteristics of waterpans

The field evaluation revealed that on-farm rainwater surface storage was common in the study area. The farm pans/ponds harvested runoff from either natural catchment located adjacent to the ponds or from road/natural water courses/footpaths/cattle-tracks. Runoff was directed into the ponds by excavated ditches.

An analysis of the 22 waterpans captured in the survey showed a variation in terms of shape, capacity and wall construction (Table 4.2).

Table 4.2 Characteristics of water pans in Matanya

Characteristics		Frequency	Percentage
Shape	Rectangular	20	91
	Round	2	9
Capacity (m ³)	30-50 m ³	6	27
	50-100 m ³	13	59
	>100 m ³	3	14
Wall	Lined	2	9
	Unlined	20	91

The pans were of different shapes and sizes with capacities ranging from 30 to over 100m³ but the majority ranged between 50 to 100m³ (59%). According to Macharia et al. (2009), run-off harvesting into pans/ponds was gaining popularity among individual farmers in Matanya for farming. Runoff was collected from grazing land, uncultivated land, cultivated land and road drainage and directed into small manually constructed reservoirs (50–200 m³).

The pans were also used in some occasions to water the livestock and more recently, fish farming. Most of the farm pans were not performing as intended in terms of harvesting and storing adequate runoff to meet the water demands.

The small capacity could mainly be attributed to siltation as the trenches directing the water into the pans were rarely having silt traps and thus the runoff that was silt loaded emptied its contents into the pan. Another cause of siltation was the unstable walls that were rarely sloped during construction/excavation. These findings agreed with Thome (2005) who reported that the reliability of the storage systems in Laikipia were reduced by high seepage and evaporation losses, which on average accounted for 30-50% of the total water stored and that this was one of the factors that affected the adoption and up-scaling of on-farm water storage systems.

The survey done in the study area one month after the cessation of the rains to the 22 waterpans found out that only 11(50%) had water that farmers were using to grow various vegetable crops. Therefore, apart from their capacity, the stored water was not adequate to meet the crop water demand. Thome (2005) observed that some farmers had abandoned their farm ponds claiming they were not useful as they only stored water during the wet season due to seepage. The author reported that ultra-violet resistant plastic lining was one of the promising cost-effective seepage control option as had been evaluated and the results were encouraging, in terms of reducing seepage water losses.

To curb the water loss through seepage, some farmers in Matanya had invested in lining of the pans using ultra-violet polythene sheets (Plate 4.1). However due to the high cost

of the lining materials, only a small proportion of farmers (9%) had invested in lining of their waterpans. These materials were either new or recycled from greenhouses. For the latter, farmers sourced them from the nearby numerous large scale farms. The farmers opted for the latter if they were in fair condition as they were cheaper. This agreed with Cherogony (2000) who reported that the high cost of good-quality plastic lining, which often needed to be factory-made to measure, was a major constraint for smallholder farmers.



Plate 4.1 A water pan lined with polythene sheet to reduce seepage loss

4.1.2 Benefits associated with the adoption of RWH technologies

Both key informants and the interviewed farmers alluded to a number of benefits that had resulted from the adoption of the RWH technologies. The benefits could be categorized into socio-economic and environmental benefits (Mutekwa and Kusangaya, 2006). Within these categories both direct and indirect benefits could be identified. Table 4.3 presents some of the socio-economic and environmental benefits brought about by the adopted RWH technologies.

Table 4.3 Benefits of rainwater harvesting

Type of benefit	Frequency	Percentage
Increased yields	63	79
Reduced soil erosion	18	23
Reduced production costs	11	14
Increased soil fertility	2	2

The farmers were able to identify advantages of using the various rainwater harvesting technologies that they used and these included increased yields, increased soil fertility, reduced production costs and reduced soil erosion. Sixty three (67%) of the interviewed farmers were aware that the use of RWH technologies resulted in increased crop yields while 23% reported reduced soil erosion in their fields through harvesting runoff water. However, only 2% of the farmers would link RWH technologies to improved soil fertility. In Lare, Nakuru, Mati (2005) reported that the adoption of ponds had improved livelihoods of the communities through increased food and water security.

Small scale farmers in Chimvi (Zimbabwe) reported similar benefits of increased crop production (89%), reduction of soil erosion (87%), maintenance of soil fertility (82%) and introduction of new crops (77%) (Mutekwa and Kusangaya, 2006).

The choice of the technology to adopt by the farmers depended on various factors that came out during the survey and group discussions with extension service providers, farmer groups and development committees (Table 4.4).

Table 4.4 Factors influencing choice of RWH technology among farmers in Matanya.

Factor	Frequency	Percentage
Ease of incorporation into the cropping system	83	93
Realize immediate benefits	28	32
Mitigate against water shortages	24	27
Incentives and/or disincentives offered	20	22
Conflict with farmers farming system	9	10

The ease of incorporation into the cropping system the farmers used was evident with the use of ridges/furrows and small pits which were highly adopted. These RWH technologies were easily applied in the husbandry practices of the three major crops grown in the area i.e. maize, beans and Irish potatoes. However, Mmbanga and Lyamchai (2001) found out that the cost of making tie ridging was estimated at 33% higher than conventional land preparation using hand hoes in Tanzania and thus small pits were recommended to farmers with scarce resources.

Whether the farmers could easily identify the immediate benefits accruing from the use of the technology like increased yields or soil erosion prevention ranked second. This was the reason why terracing had gained popularity as the structures prevented soil erosion within the farms during times of high rainfall intensity that were common in the area. On the contrary, farmers claimed that they were abandoning Conservation Agriculture (CA)/Conservation Tillage (CT) after a season or two after realizing little or no significance yields with those not practicing CA/CT. Steiner (2002) observed that though CA/CT systems had several advantages, it needed an understanding of the concept and required careful farm management practices to be successful. The conflict or competition the technology posed to the farming system the farmers adopted was reported with CA. Although mulching in CA/CT had an effect on evaporation losses, the adoption by the farmers was low due to the alternative uses for the stovers as cattle feed in Laikipia (Situma, 1997).

The effectiveness of the technology in mitigation against the water shortages was reported by farmers who had constructed waterpans. Apart from being used to mitigate against intra-season dry spells, the water was used in some cases to water the livestock.

The incentives and disincentives offered by various institutions operating in the area were reported to be an influencing factor. The incentives included a free drip kit to cover a quarter acre of land for riparian farmers who constructed water pans, a subsidized water tank for those investing in rooftop water harvesting by Naru Moru WUA and WRMA. The disincentives included stiff penalties (Ksh.80, 000) and confiscation of pumps if found illegally abstracting water from rivers by WRMA.

There was higher adoption of waterpans among the riparians farmers. Out of the 22 waterpans in the study sample, 11 were in the area served by the canal while the other 11 were outside the area. A Chi-square test on the adoption of water pans among farmers indicated that there was a significant difference between households who were previously served by the canal and those outside the area (Appendix 5). The calculated chi-square value (4.2) was greater than the table value (3.84) at $p=.05$ level of significance.

Some reasons for this difference include financial ability of the vegetable growing farmers who were beneficiaries of the canal before its collapse. The incentives inform of trainings and subsidized water tanks being offered by the Naru Moru RUA could be another reason for higher adoption. Kiteme et al. (2008) reported that the work of WUAs extended beyond conflict resolution and included water conservation through better irrigation practices such as drip irrigation, rainwater harvesting, and improved river water storage; among other measures.

4.2 Crops grown and cropping systems under rain water harvesting

4.2.1 Crops grown under RWH

The dominant types of crops that farmers in Matanya grew were the maize, beans and potatoes. Small portions of the farm were devoted to various vegetable crops like tomatoes, cabbages, kales, spinach and garden-peas. Some farmers occasionally grew

drought tolerant food crops such as sorghum, millet, pigeon peas, cowpeas and dolichos lab-lab (Table 4.5).

Table 4.5 Type of crops grown under RWH in Matanya

Type of crop grown	Frequency	With RWH	Without RWH
Maize	99	90	9
Beans	90	30	60
Irish potatoes	77	40	37
Sweet potatoes	33	28	5
Kales and spinach	11	8	3
Cabbages	9	9	0
Tomatoes	8	8	0
Garden peas	4	4	0

A large proportion of the farmers, (81%) reported that they grew the crops for home consumption while 19% reported it was for sale. Maize is a staple food crop where household food shortage is synonymous with the shortage of maize grain hence 90% of them grew the crop under RWH. In a similar study in Zimbabwe (Mutekwa and Kusangaya, 2006) where maize is a staple food crop, 100% of the respondents grew maize under RWH technologies. This is despite the fact that maize faces the greatest risk owing to its long growing period and its sensitivity to unevenly distributed rainfall (Bachmann, 1995). Despite the risk, Tegemeo (2008) reported that there had been only a small decline in the proportion of land allocated for maize in the marginal areas from 77.2% in 1997 to 74.9% in 2007.

To reduce the production risks, farmers planted crops with different water demands during their growth period. The other major food crops were potatoes and beans that were grown by 40% and 30%, respectively, of the respondents.

The vegetable crops were mainly for sale and were grown by fewer farmers (between 4-9%). In a case study of Mwala, in Machakos County, (RELMA-in-ICRAF, 2004) farmers had diversified to include horticultural cash crops and this had contributed to food

security; better nutrition and higher family income. Similarly in Zimbabwe farmers introduced new cash crops such as sugar-cane (59.7%) and vegetables (77.4%) for income generation. Nevertheless, only a few farmers grew cotton (16.1%) under RWH because it was a ‘drought-tolerant’ crop that usually does well under rain-fed dryland farming (Mutekwa and Kusangaya, 2006).

The farmers grew the various crops under different RWH technologies (Table 4.6). The survey found out that all the crops were grown under more than one RWH technology.

Table 4.6 Type of crops under different RWH technologies in Matanya

RWH technology	No. of farmers adopting	Frequency of crops grown under each RWH technology						
		Maize	Irish potato	Beans	Kales and spinach	Sweet potato	Napier grass	Others
Ridges/tied ridges/furrows	59	21	31	17	1	22	14	12
Small pits (<i>mategu</i>)	44	42	0	0	0	0	0	2
<i>Fanya juus</i>	32	3	6	2	0	10	8	5
Waterpans	22	11	12	9	12	0	0	8
Mulching/CA	10	5	4	0	3	0	0	3
Large pits (<i>tumbukiza</i>)	5	0	0	0	1	0	1	6

The importance the farmers put on food security in crop production could be deduced from the wide range of technologies adopted for the three major crops (maize, beans and potatoes) and the vegetables. Of the farmers interviewed, maize was grown under all the RWH technologies they had adopted except the large pits (*tumbukiza*). The most popular technology in maize growing was small pits (*mategu*) by 42% of the farmers or 96% who had adopted the technology. For beans the farmers had adopted three of the technologies while for potatoes and vegetables it was four each. The ridges and furrows were used by the farmers to grow virtually all the crops they were producing. The small pits had the least range of user crops though popular for maize production.

4.2.2 Cropping systems

The agricultural production of small holders in Matanya was mostly mixed. The survey found that 86 of the farmers grew crops and kept livestock while none had livestock production only (Table 4.7).

Table 4.7 Descriptive statistics of small-holder farmers in Matanya

Description	Mean	Std. deviation	Min.	Max.
Household size	6.8	2.2	2	13
Land size(acres)	3.42	3.99	0.25	34
Cropped area(acres)	1.32	0.7	0.13	4
Livestock units	2.71	3.28	0	21
Family labour	1.95	0.9	1	5

On average a farmer in Matanya had 1.3 acres of land available for crop production out of 3.4 acres of land. The farmers grew their crops either as an intercrop or as a pure stand (Figure 4.2).

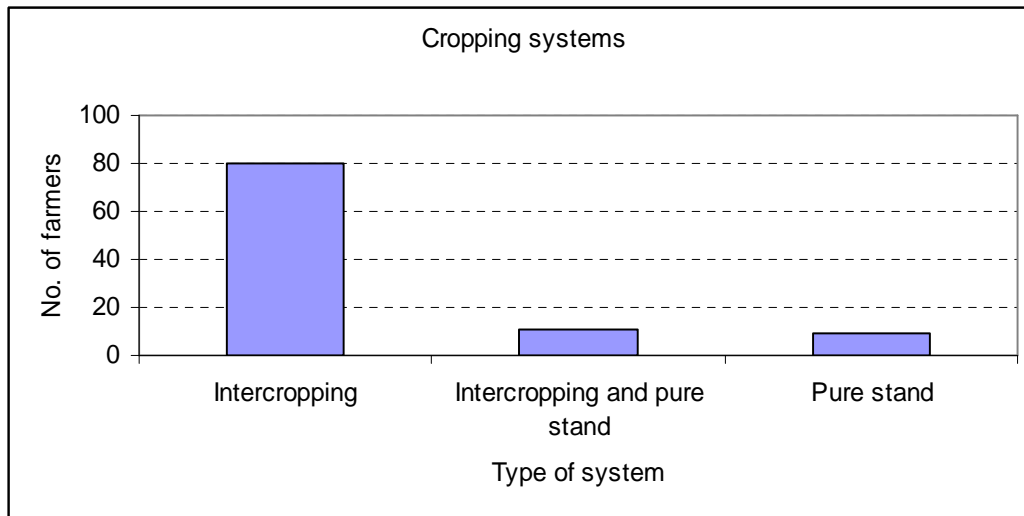


Figure 4.2 Cropping systems prevalent in Matanya

In order to maximize on the limited land available 80% of the farmers were intercropping their crops and especially the three major food crops. The most common

mix of intercrops was maize/beans, maize/irish potatoes and maize/irish potatoes/beans. This concurred with a study by Tegemeo (2008) who reported that in Kenya, intercropping maize with other crops was common among the smallholder maize farmers. Only 9% of the farmers grew their crops in a pure stand. Intercropping was very suitable for labour intensive small scale crop production (Situma, 1997) and it also contributed to reducing the production risks because several products could be cultivated simultaneously with higher total yields and better use of land i.e. acted as insurance for smallholder farmers in Laikipia. This agreed with Ngigi et al. (2005) who observed that commercial horticultural crops grown off-season under irrigation from RWH were in pure stands.

Among the farmers who practiced irrigation, the survey showed that there were three main sources of water for irrigation (Table 4.8).

Table 4.8 Source of water for irrigation in Matanya.

Source	Frequency	Percentage
Harvested rain water	17	45
Permanent river	11	29
Seasonal river/furrow	10	26
Total	38	100

Harvested rainwater into waterpans was the most important (45%) source of irrigation water in the study area. The other two sources were unreliable during the dry period when the water was needed most. Trends in river flows indicated low flows corresponded with the dry season and when irrigation water demand was highest (Aeschbacher et al., 2005). The findings in this study agreed with the conclusion by Aeschbacher et al. (2005) that increasing irrigation water demands could only be met if rainwater harvesting and management (RHM) systems (on-farm storage and construction of reservoirs along the river) were considered. Ngigi et al. (2007) noted that exploitation of the potential of RHM systems such as farm ponds/pans; earthdams, in-situ rainwater conservation and

flood diversion and storage would minimize dry season water demands and river abstractions.

The field evaluations revealed that waterpans/ponds were common in the study area and were of different sizes and shapes (Table 4.2). Despite the importance of the waterpans, their use was limited to mitigation against intra-season dry spells for the major food crops and small scale off-season commercial vegetable production.

There were several factors influencing the choice of crops farmers irrigated during the rainy and dry seasons (Table 4.9).

Table 4.9 Factors influencing the choice of crops to irrigate in Matanya.

Factor	Frequency	Percentage
Stabilization of yields	25	47
Short growing/irrigation period	18	34
High value crop	7	13
Crop diversification	3	6
Total	53	100

The stabilization of food crop yields for food security dictated on what was to be irrigated by almost half the respondents (47%) during the rainy season. Under this category, the farmers would irrigate the three major food crops namely maize, potatoes and beans. The same applied to bananas which were considered to be a minor food crop.

This was well collaborated by the type of crops that farmers irrigated from both river and water pans/ponds (Table 4.10).

Table 4.10 Type of crops that farmers irrigate in Matanya.

Type of crop	Rainy season		Dry season	
	Frequency	Percentage	Frequency	Percentage
Potatoes	13	23	0	0
Maize	12	21	0	0
Beans	10	18	0	0
Kales and spinach	10	18	1	9
Cabbage	5	9	4	37
Tomatoes	3	5	5	46
Bananas	2	3	0	0
Garden peas	2	3	2	18
Total	57	100	11	100

Income generation was the sole goal of the farmer for the water stored in waterpans during the dry season. Irrigation of the high value crops dominated during the dry period. A follow-up done after the cessation of the 2011 short rains i.e. January to March 2012 in the 22 farms that had waterpans captured in the original survey found out that farmers were using the water to irrigate various vegetable crops.

Vegetable crops grown ranged from tomatoes, cabbages, kales, spinach, and garden peas. Irrigation from the waterpans was a more reliable source of water than from rivers and canals. Vegetable crop production had become more attractive to several farmers because of a ready market (at the local and major urban centres) and had a short irrigation period. The farmers were able to plan their production calendar in order to benefit from the prime market prices.

4.3 Crop productivity for households with and without RWH systems

4.3.1 Major food crops

Within a particular season, the in-situ RWH technologies seemed to be effective in the stabilization of crop yields (Table 4.11).

Table 4.11 Average yields (kg/ha) for the major food crops during the 2011 short rains in Matanya.

Treatment	Maize	Beans	Potatoes
With RWH	259 [20]	50.4 [14]	204 [14]
Without RWH	18 [5]	18 [6]	110 [5]

Number of farmers in parenthesis

The average yields for all the three crops for the farmers using RWH technologies were higher than those without the technologies. This is consistent with Mutabazi et al. (2004) findings that farmers were more likely to experience yield risks associated with significantly reduced yields or total crop failure in below average than in average rainfall seasons. For those with RWH, the yields were 14 times, three times and two times higher than those without for maize, beans and potatoes respectively. The latter was adversely affected by waterlogging as the heavy seasonal rains were concentrated within a span of seven weeks (Appendix 3).

Evaluation of RWH systems in Laikipia District (Kihara, 2002) revealed that maize under conservation tillage did out-yield that under conventional tillage by 20 to 50% at farmers' fields. However, moisture conservation and yield improvement depended mainly on seasonal rainfall amount and distribution, soil characteristics and crop management. Yields for maize were raised from 2.18 to 2.43 ton/ha in eastern Kenya with the use of tied ridges (Itabari and Wamuongo, 2003).

Table 4.12 Variability of maize yields among farmers practicing and those not practicing RWH in Matanya

		Number of farmers	Average maize yields (kg/ha)	Minimum yields(kg/ha)	Maximum yields(kg/ha)	Std. deviation	CoV
With RWH technologies		20	259	135	630	106	41%
Without RWH technologies		5	18	0	45	22	122%

Variability among those not practicing RWH (CoV of 122%) was about four times when compared to those with RWH (CoV of 41%). This indicated that the use of RWH assisted in stabilization of crop yields.

The adoption of RWH technologies by the farmers thus seemed to mitigate crop yields against varying seasonal rainfall. These technologies helped to mitigate the effects of intra- and off-seasonal dry spells through maximizing plant water availability (maximize infiltration of rainfall), minimize unproductive water losses (evaporation, deep percolation and surface runoff), increase soil water holding capacity, and maximize root depth) (Rockström et al., 2001).

The implication of this difference in maize yields for those with and without RWH technologies to the household food security was notable. From the survey done, the average family size in Matanya was 7 persons. For the average family, the 105 kg (from 0.4 ha) of maize would last for 40 days as compared to 3 days for 7 kg (at 135 kg/person/year) for those with and those without RWH, respectively. It is notable that production lagged behind population growth in the area to the extent that majority of smallholder farmers could not adequately provide for their livelihoods (GoK, 2004). Therefore, RWH technologies would not entirely mitigate the impacts of persistent droughts but they reduced their effects by improving and/or stabilizing crop yields.

An analysis of the yields for the three major crops was done to test whether the observed difference in yields was significant (Table 4.13).

Table 4.13 Analysis of the yield differences for the three major crops in Matanya

Treatment	Crop yields (kg ha ⁻¹)		
	Maize	Beans	Potatoes
RWH	259 ^a	50.4 ^a	204 ^a
No RWH	18 ^b	18 ^b	110 ^a
S.e.d	49.9	11.37	65.6
Lsd_{5%}	103.1	24.00	139.1
P-value	<0.001	0.011	0.170

Means followed by the same letter are not significantly different at p = 0.05

The yield difference in maize and beans for the farmers with and those not practicing RWH was significant as the p value was less than 0.05. The same was not the case for Irish potatoes. For the latter, the reduction in yields for farms with RWH structures was probably due to waterlogging witnessed during the month of November 2011 and may have been a contributing factor for the non-significant difference in Irish potatoes yields. This concurred with Mutabazi et al. (2004) that in dryland areas, too much rain (flood) and too little rain (drought) do occur in the same area in the same season. In this regard, the major problem is lack of efficient means to manage the rainwater resources rather than lack of rainfall as such. Similar observations were made by Kihara (2002) that where run-off from an external catchment was directed to the field through furrows, it was allowed to spread into the cropped area or infiltrated slowly into the soil. However, during periods of heavy and/or continuous rains there was a danger of flooding and waterlogging in the fields as the structures had no regulatory mechanisms.

A gross margin analysis on maize production for farms with and those not practicing RWH indicated a negative net income for both (Table 4.14).

Table 4.14 Gross margin analysis for maize production with and without RWH technologies

Item per hectare	Value in Ksh.	
	With RWH	Without RWH
Gross output (G.O.)	259 kg @ Ksh. 30 = 7,770	18 kg @ Ksh. 30 = 540
Recurrent costs:		
Seeds	2,250	1,500
Manure	1,000	1,000
Land prep.	3,750	3,750
Planting	3,750	3,000
Weeding	3,000	3,000
Harvesting/shelling	750	300
Total recurrent costs (TVC)	12,250	10,050
Net income = G.O. minus TVC	- 4,480	-9,510

The gross margin analysis indicated a negative value for both practices implying that it was not economical to produce maize. However, Barron et al. (2003) argued that although irrigating maize may be uneconomical, it had been shown that supplemental irrigation during flowering could substantially improve grain yields. Again, being the staple food, farmers would prefer to stabilize its production, even if only a small plot would be irrigated. Low crop yields would persist even with increased soil moisture if soil nutrients were inadequate. Fox and Rockstrom (2003) concluded that a combination of RWH and nutrient management held key to higher and sustainable agricultural productivity in semi-arid areas. Farmers in the study area would not realize the negative returns from this maize production as the bigger portion of the cost was the opportunity cost of the family labour (61% of the farmers solely relied on family labour).

4.3.2 Vegetable crops

From the survey carried out during the rainy season, farmers grew vegetable crops mainly for home consumption. The most preferred crops were the kales, spinach and garden peas. These crops were grown by those with and those without rainwater harvesting systems. However, the productivity was higher for the farmers with RWH systems (Table 4.15).

The values showed that the yields from farmers with RWH were more than double those without RWH systems. The yields from RWH were also more than double the district's average yields which were 5 t/ha for kales and 3.5 t/ha for garden peas (MoA, 2008-2011) (Appendix 6).

Table 4.15 Analysis of the mean yield differences for the three vegetable crops in Matanya.

Treatment	Crop yields (t ha ⁻¹)		
	Spinach	Kales	Garden peas
RWH	9.9 ^a	12.5 ^a	10.90 ^a
No RWH	4.6 ^a	4.80 ^a	4.20 ^b
Grand mean	7.25	8.65	7.55
S.e.d	2.52	3.84	1.12
Lsd _{5%}	10.86	12.21	4.81
P-value	0.171	0.137	0.027

Means followed by the same letter are not significantly different at $p = 0.05$

Though in all the three crops there was an increase in yields with the adoption of RWH, it was only in garden peas production that the difference in yield was significant (p value less than 0.05).

During the dry season, vegetable crop production was for commercial purpose. The most preferred crops were tomatoes (46%), cabbages (37%) and garden peas (18%). The farmers established the crops about a month before end of the rainy season. Among the factors that influenced the choice of these crops were the good prices, ready market,

experience and easy water application methods. Vegetable production was more economically viable due to higher returns, shorter growing period and high demand in semi-arid environments, which gave it preference.

In a case study of Mwala District, farmers practicing RWH were found to have diversified their crops to include horticultural cash crops and households earned US\$735(per ha) from cash crop compared with US\$146 normally earned from rainfed maize (RELMA-in-ICRAF, 2004).

Field experiments in Laikipia by Ngigi et al. (2005) showed that supplemental irrigation on cabbages on a 300 m² plot could yield 4.5 tonnes per season and valued at US\$ 405. This indicated that higher value vegetables such as tomatoes and snow peas could even result in more returns. With the waterpans, the farmers would no longer regard their pieces of land as small since RWH technologies enabled them to practice intensive farming.

In order to maximize on the stored water in water pans, the farmers were establishing the vegetable crops about a month to the end of the rain season and only irrigated for about two to three months (Ngigi et al., 2005). This ensured that the crops came into production during the dry period when the demand in the market was very high. As the farmers became more commercially oriented, they were adopting more efficient water conveyance and application methods in vegetable production (Table 4.16).

Table 4.16 Water conveyance and application methods in Matanya.

Water conveyance method	Frequency	Water application method	Frequency
Motorized pump (piping)	8	Furrow/pits	9
Hand drawn (bucket)	3	Drip	2

In the study area, the conveyance of the water from the water pans to the farm was either through piping (73%) or bucket (27%). The water application methods were furrow (82%) and drip (18%). The conveyance was advancing from hand drawn bucket method

to piping either directly into the field or into a raised water tank (Plate 4.2). Sharma and Sharma (2007) reported that major water losses (>40%) and poor uniformity in water distribution occurred due to inappropriate surface irrigation methods. They reported that adoption of drip system had enabled regions facing limited water supplies to shift from low-value crops with high water requirements, such as cereals, to high value crops with moderate water requirements, such as fruits and vegetables.



Plate 4.2 Tomato production from a low head drip irrigation system installed next to a water pan in Matanya.

Though the sizes of the waterpans varied from farm to farm, the water application methods determined the cropped area. Due to the limited stored water, farmers were shifting from the use of the wasteful furrow water application method to the efficient drip irrigation method. From a 100 m^3 water pan, the farmers using furrows were irrigating an area of about 400 m^2 , while those using drip system had an area of about 500 m^2 of a tomato crop. This concurred with Ngigi et al. (2005) who observed that improved water management through incorporation of low-head drip irrigation technology could improve the reliability of RHM systems and encourage farmers to increase their acreage under supplemental irrigation.

The yields were higher for those farmers adopting drip irrigation from furrow water application method. The drip system was earlier reported as the most efficient in terms of water application efficiency (90-98%), followed by sprinkler (80-95%) and furrow (40-60%) (Sharma and Sharma, 2007). It was also the most economical system for high-value crops, i.e. horticultural crops. This was because the drip system provided a more uniform and adequate moisture to the plants. Due to these factors, farmers reported that the crop establishment under the drip system was higher (80%) compared to about 60% under the furrow system.

Though there was a yield increase with RWH and adoption of efficient water application methods, production was only possible in small acreages due to the limited amount of water the farmers were able to store in the waterpans. For instance, from a 100m³ waterpan only an area of 400m² using the conventional furrow water application method was irrigable. In a season, farmers were making returns of Ksh.17, 900 and Ksh.6, 200 from tomatoes and cabbages respectively (Table 4.17). This implied that from the same volume of water, production of tomatoes gave better returns. These returns were based on the average farm gate prices the produce fetched during the months of March and April 2012 (Ksh.30-50 per kg of tomatoes and 35-45 per head for cabbages).

Table 4.17 Gross margin analysis for tomatoes and cabbages under furrow irrigated from a 100m³ water pan in Matanya.

Value in Ksh.		
Item per 400 m ² plot	Tomatoes	Cabbages
Gross income	720 kg @ Ksh. 40 = 28,800	740 kg @ Ksh. 20 =14,800
Recurrent costs:		
Seeds	400	600
Fertilizers	2,000	2,000
Pesticides	1,500	1,000
Staking	2,000	0
Labour	4,000	2,000
Fuel (water)	3,000	3,000
Total recurrent costs	10,900	8,600
Net income	17,900	6,200

The effectiveness of this RWH system was affected by the low storage capacities, which was constrained by high construction costs and farmers' low income. To control seepage, Cherogony (2000) suggested that cheaper methods such as clay grouting should be encouraged rather than the high cost of good-quality plastic lining which was a major constraint for smallholder farmers.

However, few financially endowed farmers in the study area were investing in ultraviolet resistant plastic lining to reduce the seepage losses which had been a major drawback to the water storage structures in the area. They then installed a low head drip system to improve on the field water application efficiency.

The lining of the waterpan and the installation of a drip irrigation system was a costly undertaking for the resource poor farmer. However, its benefits/output outweighed the costs involved (Table 4.18).

Table 4.18 Return to investment from a 100m³ water pan for tomato production in Matanya.

Item	Value in Ksh. per 500m ² plot	Value in Ksh. per 400m ² plot
Investment costs:		
Tank and drip system @ Ksh. 40,000	=40,000	
UV resistant plastic lining: 120 m ² @ Ksh.85 per m ²	=10,000	
Loan interest rate @ 25% p.a.	=12,500	
Total investment costs	62,500	0
Recurrent costs: Seeds	400	400
Fertilizers	2,500	2,000
Pesticides	2,500	1,500
Staking	2,000	2,000
Labour	4,000	4,000
Fuel	3,000	3,000
Total Recurrent costs	14,400	10,900
Total cost	76,900	10,900
Production (kg)	2,230	720
Gross income @ Ksh. 40/=	89,200	28,800
Net income season 1	12,300	17,900
Net income per season in subsequent seasons (gross income minus total recurrent costs)	74,800	17,900

A farmer who invested in the lining of their waterpan and installed the drip system would have a net income of Ksh. 12,300 against Ksh. 17,900 for those without the investment during the first season. However, during the subsequent seasons, the farmer would be earning Ksh.78, 400 as compared to the constant Ksh.17, 900 per season for those not investing. This was as a result of reduced water losses through seepage thus a farmer was

able to irrigate a bigger area and an efficient water application method to the crop resulting in higher yields.

Fox and Rockstrom (2003) reported that in Mwala (Machakos) with maize production, depending on how labour cost was estimated, the structure and system of supplemental irrigation and fertilizer were estimated to provide household food self-sufficiency and net income after 1–7 years with the most profitable estimate was for no labour cost and thin plastic sheeting as a sealant.

Therefore, on-farm RW storage system was a viable investment in semi-arid areas, which experience persistent crop failures, food shortages and poverty. The prices of vegetables increased during the dry seasons, which meant that with RWH, farmers could plan their crop production to coincide with high market prices. This concurred with Singh (2007) who reported that the water harvesting and supplemental irrigation system was more economically viable with vegetables, fruits and other high-value crops and that even at 14% interest; the entire initial investment could be recovered in a period of 2–3 years.

The higher net returns from crop production would enable farmers improve their living standards as well as invest in other income generating activities. Some farmers in Matanya had adopted the greenhouse technology (Plate 4.3). The greenhouses were a water harvesting catchment into the waterpans that would boost the amount of water available for crop production. Such an investment could also improve crop productivity, as a crop would be in production for a long period, it would be possible to have more cropping seasons in one year and grow a wider range of crops.



Plate 4.3 A successful RWH technology farmer's green house and water pan

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study was carried out to document rainwater harvesting practices, cropping systems and crop productivity by smallholder farmers in Laikipia Central District. The findings of this study indicated that:

1. The major RWH practices adopted by smallholder farmers in Laikipia Central District were ridges/tied ridges/furrows, small pits (*mategu*), *fanya juus*, waterpans/ponds, mulching, conservation tillage/agriculture and large pits (*tumbukiza*)
2. The crops grown under rainwater harvesting practices are maize, beans, irish potatoes, and sweet potatoes as the food crops while cabbages, tomatoes, kales, spinach and garden peas are the main commercial crops
3. The most common cropping system among the smallholders was intercropping (over 90%) as compared to 9% practicing pure stand cropping system. The most common mix of intercrops were maize/beans, maize/potatoes, maize/potatoes/beans.
4. The average yields for the farmers using RWH practices were at least two times higher than those of farmers not practicing RWH for all the major food and vegetable crops.

5.2 Recommendations

1. RWH technologies should be promoted in Laikipia Central District as a strategy of addressing food insecurity and income generation as they were found to significantly improve agricultural productivity.
2. Development agencies should mobilize and support households to ensure that they invested in improved RWH storage systems such as lining with polythene sheet to reduce seepage losses.
3. The use of rainwater management systems such as drip irrigation should be promoted to ensure efficient utilization of available water for crop production

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APPENDIX

Appendix 1 Questionnaire used in the study

Identification

Name of the enumerator.....

Name of the respondent.....

District.....Division.....Location.....

Date.....Start time.....Block.....

Household characteristics

Age of the farmer.....

Gender (0) female (1) male

Marital status (1) single (2) married (3) widow/widower

Formal education level (years).....

None (2) primary (3) secondary (4) college/university (5) adult education

Total number of children.....

Total number of family members who work on the farm.....

Are there family members who work off-farm? (0) no (1) yes

If yes, how many?

Farm characteristics

When did you start farming on this piece of land?.....years

What is the size of farm in acres?

What is the ownership status: (1) Owner (2) leased out (3) Worker/ Labourer (4) Squatter (5) Others (specify)

If own farm, how did you acquire it? (1) bought (2) inheritance (3) Others (specify)

What is the total available land for crop production in acres?

Which crops do you grow?

Are the crops in (1) pure stand (2) intercropped (3) both?

Do you cultivate crops for sale? (0) no (1) yes

If yes, which ones and how much land is usually allocated to each?

Crop	acreage	yield (average year-short rains 2009)
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What is the total available land for the 3 major food crops in acres?

Crop acreage yield (average year-short rains 2009)

How long does the stored produce last? (1) One month after harvest (2) 2 to 3 months (3) less than six months (4) Six/ more than six months (5) all the year

Apart from own production, how else do you obtain food for your household? (1) purchase from the market (2) remittances from relatives (3) famine relief

If the answer to 2.12 is (1), what is the source of income (1) sale of farm produce (2) off-farm employment (3) business/jua kali (4) Others, (specify)

Do you keep livestock?

If yes, which types of livestock for the past one year (2011)?

Type number average production consumed sold unit price

What is your source of livestock feed (2011)? (1) own farm (2) unsettled farms (3) leased farm (4) off-farm purchases

Do you use hired labor? (0) no (1) yes

If hired is it (1) temporary (2) permanent (3) both

What is the cost of labor per man-day?

Do you use fertilizers and/or manure in your farm? (0) none (1) fertilizer (2) manure (3) fertilizer and manure

If the answer to 2.20 is (0), why do you not use them? (1) lack of information (2) are not available (3) difficult to apply (4) expensive (5) other (specify)

What agriculture inputs do you use and for which crops?

Crop type of input rate of application price

- 1.
- 2.
- 3.

Soil and water conservation technologies

Do you practice irrigation or just rain fed agriculture? (1) irrigation (2) rain fed agriculture (3) Both

If irrigation, from what nature of water source? (1) permanent (2) seasonal (3) harvested rain water

What size of land do you irrigate?

What crops do you irrigate?

Why these crops?

How long does the water supply last; (i) less than 1 month after the rains; (ii) 2 to 3 months (iii) 6 months; (iv) throughout the year

How is the water conveyed to the field? (1) furrow (2) piped-gravity flow (3) piped- motorized pump (4) other (specify)

How do you apply the water? (1) basin (2) sprinkler (3) drip (4) furrows/ridges (5) other (specify)

If rain-fed, do you experience reduced yields or crop failure? (0) no (1) yes

Do you practice rain water harvesting? (0) no (1) yes

If yes, what method(s) do you use? (1) in-field soil and water management (2) surface storage.....

If the answer to 3.11 is (1), what techniques do you use and on which crops and why?

Technique	crops grown	Reason(s)
-----------	-------------	-----------

(1) Fanya juus-

(2) Tied ridges/furrows-

(3) Mulching-

(4) Tumbukiza-

(5) Micro-catchments (pits)-

(6) Other-

If surface storage, how is the water drawn and conveyed to the field? (1) bucket (2) manual pump (3) motorized pump (4) other (specify)

How do you apply the water in the field? (1) basin (2) sprinkler (3) drip (4) furrows/ridges (5) other (specify)

What area of land is under rain-water harvesting in acres?

If the answer to part 3.10 is no, why do you not use rain-water harvesting? (1) lack of information (2) land constraint (3) laborious (4) expensive (5) not interested (6) other (specify)

What are the benefits of using rain-water harvesting? (1) increased yields (2) increased soil fertility (3) reduced production costs (4) reduced soil erosion (5) other (specify)

In how many seasons have you had crop failure for the last 4 seasons? (1) 1 season (2) 2 seasons (3) 3 seasons (4) 4 seasons

What coping strategies have you adopted in farming due to persistent crop failures ?(1) none (2) adopted drought tolerant crops (3) changed to livestock rearing (4) Irrigation (5) rain water harvesting (6) crop insurance (7) change of planting dates (8) other(specify)

What other challenges do you encounter in crop production and how do you cope? Fill in the table below:

Crop production Challenges	Coping Mechanism
(i)	(i)

Extension and social capital

Have you ever had contact with any extension service? (0) no (1) yes

If yes, which organization(s)?

Have you received any information on rain-water harvesting from any extension group?

If yes, what sort of information?

Have you been trained on how to practice rain-water harvesting by any extension group? (0) no (1) yes

If yes, what method were you trained on?

Which of the trained method do you practice?

Are you a member of any rain water harvesting farmers group? (0) no (1) yes

If yes, state the farmer group and its activities.....

Water availability

What is the main source of water for this household? (1) piped (2) river (3) well (4) rain water (5) bore hole

How long does it take to collect water if its not within the farm?.....hours

Do you use the water to irrigate your crops? (0) no (1) yes

If yes what crops?

If the answer to part 5.1 is 1 or 2, for how many months in a year is the water not reliable?

Farm production

List the most important horticultural crop enterprises in the year 2011

Short rains (mid oct.2011 to Jan. 2012)

Crop acreage total output price/kg total income

1.

2.

3.

Farm implements/equipments

List the types of implements/equipments the farmer has for rain-water harvesting practices

a)

b)

c)

Income and expenditure

Apart from farming what are the other sources of your household income? (1) salaried employment (2) casual labor (3) business/jua kali (4) other (specify)

What amounts are allocated to food and non-food items?

Type of item	amount per month
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Appendix 2 Long term rainfall data (1943-2010) from Lengetia farm

YR	JAN	FEB	MARCH	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1943	16.5	15	6.9	73.9	29	6.6	68.6	31	25	49.3	70.4	123	515.1
1944													
1945													
1946													
1947	24.9	17.5	83.8	115	58	12.7	51.6	28	2.5	19.1	107	197	717.8
1948	5.1	0	31.5	66.8	6.9	16.3	53.8	4.6	18	24.1	86.6	91.7	405.7
1949													
1950													
1951	39.4	25.7	197.4	199	42	38.9	113	51	33	174	189	157	1259
1952	42.7	17.3	58.7	121	38	0	30.5	27	24	46.2	71.9	116	593.3
1953													
1954													
1955	149	13.2	64.3	87.4	20	3.6	30.2	95	85	54.6	52.1	101	754.5
1956	125	14.2	76.7	80	44	21.1	82.3	55	24	54.1	74.7	149	800.1
1957	39.1	57.9	61.7	148	96	9.7	5.3	22	31	32.5	209	155	867
1958	65.3	52.8	76.7	54.6	110	48	82.6	11	18	59.4	38.4	167	783.9
1959	53.8	25.4	60.7	23.6	102	19.3	62.7	6.1	7.9	69.3	111	38.1	580.1
1960	66.5	13.7	131.8	82.8	17	3.6	11.2	68	26	85.9	47	96.8	649.6
1961	22.9	28.4	138.4	148	58	2	4.3	79	265	368	343	102	1558
1962	142	22.9	59.7	85.1	96	38.1	23.6	21	52	136	105	122	901.5
1963	94.7	52.3	56.9	182	123	7.6	6.4	55	0	42.9	257	210	1088
1964	8.6	47.5	57.2	227	30	43.4	55.4	67	79	70.6	63.5	118	866.9
1965	102	8.6	46	108	24	41.1	9.4	10	7.4	35.8	76.2	23.6	492.3
1966	16.5	31.2	142.2	96	40	38.6	24.1	76	0	61.2	105	4.3	635
1967	29.5	29.5	117.1	145	81	18.3	62.7	21	20	141	135	6.4	805.8
1968	0	150	163.1	206	29	44.2	13.7	2.8	0	81.5	198	112	999.5
1969	81.3	148	155.2	89.9	0	82.3	0	38	85	60.2	96.8	82.8	919

1970	94.2	0	129.5	139	46	21.8	20.3	14	12	18.5	126	17	639.5
1971	51.6	0	36.1	158	42	10.4	8.6	154	26	41.4	98.4	109	735
1972	59.7	71.6	40.1	24.1	44	69.6	8.9	11	42	103	59.7	36.1	569.2
1973	49.8	32.3	43.2	74.7	7.1	6.9	40.4	30	61	33	130	39.6	548
1974	28.2	39.6	66.5	147	20	0	43.9	76	2	30.2	118	26.4	597.5
1975	29	43.4	103.1	78.2	17	77.2	56.9	57	61	50	88.1	30.5	690.8
1976	0	93.7	41.4	96.8	65	12.7	69.6	24	17	38.1	92.5	130	680.3
1977	46	102	47.2	145	52	22.9	83.1	26	7.4	31.2	167	61	790.9
1978	66.5	184	135.6	39.1	18	7.9	33.8	37	55	84.3	74.2	214	948.1
1979	158	115	69.6	64	43	7.4	16.5	22	45	71.6	157	15.2	784.5
1980	9.9	29.5	101.3	68.3	55	14.2	0	0	18	90.2	90.2	39.4	515.9
1981	39.6	48.8	56.9	47.5	133	0	135	22	37	74.7	67.8	116	777
1982	32.5	17.5	33.5	154	36	31.2	0	60	16	169	162	86.1	797.9
1983	3.3	84.3	29.2	90.4	0	45.5	67.3	67	14	53.1	28.2	104	586.4
1984	14.7	23.1	74.2	51.8	0	0	6.1	0	57	137	150	69.6	583.5
1985	71.4	75.4	133.9	69.9	24	0	36.8	0	72	131	86.6	51.3	752.8
1986	29.5	8.1	59.2	122	21	36.8	58.2	21	10	36.3	401	77.2	881.5
1987	38.4	31.5	43.4	112	47	66.3	4.8	13	27	33	153	78.2	646.9
1988	42.4	69.9	103.1	154	0	83.6	88.6	55	44	84.8	119	179	1023
1989	31.8	78	91.9	154	0	0	78	31	40	89.7	140	94.7	828.8
1990	75.2	91.7	148.8	111	93	4.6	4.1	14	12	61.2	61	122	798.9
1991	43.9	39.9	117.3	114	25	97.5	6.1	106	0	15	59.4	85.6	709.8
1992	59.2	43.2	22.9	110	12	0	0	0	0	48.8	110	120	525.9
1993	197	80.3	45.5	18.5	34	66.8	3	8.6	0	104	103	56.1	717
1994	0	13.2	106.2	111	20	41.9	27.9	50	25	69.6	262	26.9	753.9
1995	14.5	40.4	90.4	74.7	75	37.3	28.2	28	50	72.6	80.3	111	702
1996	35.6	45.2	39.1	69.9	7.4	128	27.7	72	4.3	70.6	178	73.9	751.4
1997	35.8	0	95.8	158	31	20.8	110	52	0	96.3	239	108	945.9
1998	249	63.5	167.9	79.2	94	41.1	20.8	59	10	90.7	46.7	40.6	962.7

1999	52.3	18.8	139.4	0	0	0	0	0	0	18.5	155	29	413
2000	37.5	3	46.5	82	31	17	19.5	21	14	24.7	77.1	60.1	431.9
2001	73	54.6	66.5	74	3.5	44	5.5	8.2	31	66.5	194	34.8	655.6
2002	59.8	2	119.1	133	166	6.5	4	0	7.5	38.6	136	85.8	758.9
2003	49.5	12	83.3	199	121	18.5	13.5	187	0	70.3	155	74	982
2004	133	41.4	89	130	98	2	42.9	17	13	75.2	64.3	23	727.5
2005	76.7	0	117.2	118	82	9.7	0	27	125	45	154	32.5	786
2006	54.9	63.3	134.6	80.8	74	6.5	0	76	4.6	21.6	150	134	799.5
2007	72.5	46.6	40.4	154	34	99.9	123	80	108	170	162	14	1103
2008	71.8	8.9	84.6	69.3	9.4	2.5	41.1	10	66	43.6	141	32.9	581.1
2009	54	5	55.9	33.7	59	15.7	0	0	14	42.7	55	191	526.2
2010	56.2	116	225.2	169	154	41	12.1	31	34	74.9	154	64.3	1132
High	249	184	225.2	227	166	128	135	187	265	368	401	214	1558
Low	0	0	6.9	0	0	0	0	0	0	15	28.2	4.3	405.7
Average	57.7	44.4	86.2	105.2	48.1	28.1	35	38.2	32.5	71.9	125.9	86.3	759.6

Appendix 3 Daily rainfall (mm)for Matanya, 2003-2011

Rainfall date	2003.0	2004	2005	2006	2009	2010	2011
1/1/	0.0	0.0	0.0	0.0		4.6	7.5
1/2/	0.0	8.3	0.0	0.4		15.0	0.0
1/3/	0.0	0.0	0.0	7.7		0.0	0.0
1/4/	0.0	0.0	0.0	0.0		1.0	0.0
1/5/	0.0	0.0	0.0	0.0		0.0	0.0
1/6/	0.0	0.0	0.0	0.0		0.0	0.0
1/7/	0.0	0.0	0.0	0.0		0.0	0.0
1/8/	0.0	0.1	0.0	5.2		0.0	0.0
1/9/	0.0	0.1	1.4	0.0		4.5	0.0
1/10/	0.0	0.0	0.0	0.0		3.6	0.0
1/11/	0.0	0.1	1.1	0.0		0.0	0.0
1/12/	0.0	10.0	0.0	0.0		0.0	0.0
1/13/	0.0	0.1	0.0	3.7		0.0	0.0
1/14/	0.0	3.2	0.0	0.0		0.0	0.0
1/15/	0.0	11.5	0.0	0.0		0.0	0.0
1/16/	0.0	1.2	0.0	0.0		16.0	1.1
1/17/	0.0	4.0	0.5	0.0		0.0	0.0
1/18/	1.4	1.1	0.0	3.2		0.0	0.0
1/19/	7.0	0.0	0.0	0.0		0.4	0.0
1/20/	18.1	0.0	0.0	0.0		0.0	0.0
1/21/	6.5	0.0	0.0	2.3		0.0	0.0
1/22/	5.6	1.2	0.0	0.0		0.0	0.0
1/23/	5.2	0.0	0.0	0.0		0.0	3.3
1/24/	0.0	11.8	0.0	0.0		0.0	0.0
1/25/	0.0	0.0	0.0	0.0		0.0	0.0

1/26/	0.0	0.0	10.0	0.0		0.0	0.0
1/27/	0.0	0.0	0.0	0.0		0.0	0.0
1/28/	0.0	0.0	4.5	0.0		0.0	0.0
1/29/	0.0	0.0	2.2	0.0		0.0	0.5
1/30/	0.0	0.0	8.5	0.0		0.0	0.0
1/31/	0.0	0.0	1.1	7.4		0.0	0.0
1/2/	0.0	0.0	0.0	0.0		0.0	9.1
2/2/	0.0	2.2	0.0	0.0		0.0	0.0
2/3/	0.0	3.2	0.0	0.0		0.0	0.0
2/4/	0.0	0.0	0.0	0.0		3.0	0.0
2/5/	0.0	0.0	0.0	0.6		17.3	0.0
2/6/	0.0	0.0	0.0	0.0		1.6	0.0
2/7/	0.0	0.0	0.0	0.0		3.7	0.0
2/8/	0.0	0.9	0.0	0.0		0.0	0.0
2/9/	0.0	10.0	0.0	0.0		0.0	0.0
2/10/	0.0	0.0	0.0	7.1		0.0	0.0
2/11/	0.0	0.0	0.0	0.0		2.6	0.0
2/12/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/13/	0.0	0.0	0.0	0.0	0.0	0.6	6.8
2/14/	0.0	0.1	0.0	0.0	0.0	0.0	0.0
2/15/	0.0	1.5	0.0	0.0	0.0	0.0	14.7
2/16/	1.7	0.1	0.0	0.0	5.4	17.3	2.0
2/17/	0.0	0.6	0.0	0.0	0.0	3.3	0.0
2/18/	0.0	0.0	0.0	0.0	0.0	0.7	0.0
2/19/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/	0.0	0.0	0.0	7.5	0.0	27.5	0.0
2/21/	0.0	0.0	0.0	9.5	0.0	1.4	0.0
2/22/	0.0	0.6	0.0	4.7	0.0	8.0	0.0

2/23/	0.0	0.0	0.0	0.0	0.0	4.6	0.0
2/24/	0.0	0.0	0.0	0.0	1.5	0.0	0.0
2/25/	0.0	0.1	0.0	3.0	0.0	3.4	0.0
2/26/	0.0	14.0	0.0	0.0	2.1	0.0	0.0
2/27/	0.0	0.0	0.0	0.0	16.3	1.1	0.0
2/28/	0.0	0.0	0.0	0.0	2.3	17.6	0.0
3/1/	0.0	0.0	0.0	35.8	0.0	3.4	0.0
3/2/	0.0	0.0	9.0	4.3	0.0	0.5	0.0
3/3/	0.0	0.0	0.0	51.0	1.1	21.0	0.0
3/4/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3/5/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3/6/	0.0	0.0	0.0	1.5	0.0	7.5	0.0
3/7/	0.0	0.0	7.2	0.0	0.0	0.3	0.0
3/8/	0.0	0.0	23.0	9.2	0.0	0.5	0.0
3/9/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3/10/	0.0	0.0	0.0	0.0	0.0	0.5	0.0
3/11/	3.0	0.0	0.0	3.2	1.9	0.0	0.0
3/12/	0.0	2.6	15.4	14.9	0.0	0.0	0.0
3/13/	0.0	0.1	1.0	0.0	0.0	0.0	0.0
3/14/	0.7	0.0	16.0	0.0	0.0	0.0	0.0
3/15/	2.5	0.0	1.4	1.4	0.0	0.0	0.0
3/16/	4.8	0.0	2.6	0.0	0.0	0.0	0.6
3/17/	2.0	0.0	8.5	0.0	0.0	0.0	22.5
3/18/	1.3	1.4	0.5	2.0	0.0	1.2	4.1
3/19/	0.0	0.0	13.7	0.0	0.0	0.0	5.9
3/20/	0.0	32.5	2.2	0.0	0.0	43.4	0.0
3/21/	0.0	0.0	0.0	0.0	0.0	3.2	6.3
3/22/	0.6	0.0	1.5	15.0	0.0	0.0	0.0

3/23/	0.1	0.0	0.0	0.0	0.0	7.8	0.0
3/24/	2.5	0.0	0.0	0.0	0.0	1.2	0.0
3/25/	0.2	0.0	0.0	15.5	0.0	0.0	3.5
3/26/	10.0	8.0	0.0	3.4	0.0	3.7	0.0
3/27/	8.8	0.0	0.0	0.0	0.0	2.9	3.0
3/28/	4.8	7.5	0.0	0.0	0.0	6.5	0.0
3/29/	4.8	0.1	0.1	0.0	0.0	1.8	0.0
3/30/	1.8	3.0	10.0	0.0	25.5	0.0	0.0
3/31/	5.0	1.6	0.0	0.0	1.9	20.6	6.5
4/1/	2.4	19.0	0.0	0.0	5.3	1.8	0.0
4/2/	0.0	0.8	0.0	0.0	0.0	15.7	1.1
4/3/	14.4	6.0	0.0	0.0	0.0	44.9	0.0
4/4/	6.5	5.7	0.0	0.0	0.0	12.4	0.0
4/5/	0.0	0.0	13.5	7.0	1.1	0.0	0.0
4/6/	0.0	2.0	42.5	18.0	0.0	1.4	3.2
4/7/	0.0	0.0	0.0	15.0	0.0	1.6	0.0
4/8/	0.0	3.0	8.4	14.5	0.0	0.0	1.0
4/9/	0.0	27.5	0.0	20.0	0.0	15.5	0.0
4/10/	0.0	0.0	5.8	6.2	0.0	0.0	0.0
4/11/	0.0	9.2	1.6	3.1	0.0	0.0	0.0
4/12/	0.0	5.6	0.0	10.6	1.0	0.0	0.0
4/13/	0.0	1.0	0.1	4.0	0.0	0.0	0.0
4/14/	1.2	13.2	0.0	0.0	0.0	0.0	0.0
4/15/	0.0	0.1	0.0	0.0	0.0	0.0	0.0
4/16/	0.6	0.0	5.2	0.0	0.0	4.0	7.7
4/17/	0.7	0.1	0.0	0.0	6.1	2.6	0.0
4/18/	1.0	9.7	0.0	0.0	1.1	0.0	0.0
4/19/	46.0	0.0	0.0	0.0	0.0	1.8	0.0

4/20/	0.0	0.0	0.0	3.5	0.0	0.0	0.0
4/21/	22.1	0.0	8.3	0.0	2.0	0.0	0.0
4/22/	0.0	16.3	0.1	19.2	0.0	0.0	0.5
4/23/	1.1	0.0	0.0	0.0	0.0	0.0	0.0
4/24/	0.0	0.0	0.0	2.2	0.0	4.6	0.0
4/25/	0.0	0.5	0.0	1.1	7.4	0.0	0.0
4/26/	0.0	1.6	0.0	0.0	0.0	0.0	0.0
4/27/	0.1	0.0	0.0	0.0	4.2	0.0	0.0
4/28/	46.0	0.0	9.2	0.0	0.0	6.3	0.0
4/29/	15.2	0.0	24.0	0.0	0.0	14.5	0.0
4/30/	20.2	5.2	7.8	0.0	0.0	0.6	5.0
5/1/	0.0	4.0	0.0	3.9	26.9	4.0	0.0
5/2/	5.1	0.0	0.0	1.1	0.0	0.9	0.0
5/3/	19.5	1.4	0.0	9.8	0.0	0.0	8.8
5/4/	3.1	25.4	0.0	2.2	0.0	5.7	0.5
5/5/	1.2	9.5	0.0	0.0	0.0	0.0	12.2
5/6/	61.0	1.0	0.7	0.0	4.1	0.0	8.2
5/7/	7.7	12.0	0.0	0.0	0.0	0.0	0.0
5/8/	19.2	0.0	0.0	35.2	0.0	0.0	0.0
5/9/	19.5	0.0	10.3	1.2	0.0	0.0	0.0
5/10/	8.7	0.0	0.0	0.0	0.0	22.2	0.0
5/11/	24.6	0.0	0.0	0.0	4.1	3.3	0.0
5/12/	0.0	0.0	0.0	0.0	3.2	1.3	0.0
5/13/	0.0	0.0	11.8	0.0	17.2	0.0	0.0
5/14/	1.0	0.0	0.0	6.0	0.0	0.0	0.0
5/15/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5/16/	0.0	0.0	0.0	1.4	0.0	0.0	0.0
5/17/	0.0	0.0	0.0	0.0	0.0	15.5	0.0

5/18/	0.0	0.0	0.0	6.0	0.0	0.0	0.0
5/19/	0.0	0.0	0.0	2.4	0.0	0.0	0.0
5/20/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5/21/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5/22/	1.5	0.0	0.0	0.0	0.0	0.0	0.0
5/23/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5/24/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5/25/	3.0	0.0	4.4	0.0	0.0	0.0	0.0
5/26/	0.0	0.0	25.6	21.0	0.0	0.0	0.0
5/27/	0.0	0.0	0.0	0.0	8.3	0.0	0.0
5/28/	0.0	0.0	3.5	0.0	19.5	0.0	0.0
5/29/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5/30/	0.0	0.0	19.0	0.0	0.0	0.0	0.0
5/31/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/1/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/2/	0.5	0.0	0.0	0.0	0.0	0.0	0.0
6/3/	9.6	0.0	0.0	0.0	0.0	0.0	0.0
6/4/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/5/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/6/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/7/	27.0	0.0	0.0	0.0	0.0	0.0	0.0
6/8/	0.0	0.0	1.5	0.0	0.0	0.0	0.0
6/9/	8.2	0.0	0.0	0.0	0.0	0.0	0.0
6/10/	0.0	0.0	9.2	0.0	0.0	0.0	0.0
6/11/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/12/	0.0	0.0	0.0	0.0	0.0	4.0	26.7
6/13/	0.0	0.0	0.0	0.0	0.0	10.4	15.5
6/14/	0.0	0.0	0.0	0.0	0.0	0.0	34.5

6/15/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/16/	0.0	0.8	0.0	0.0	0.0	0.0	0.0
6/17/	16.3	0.0	0.0	0.0	0.0	0.0	0.0
6/18/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/19/	0.0	0.0	5.0	0.0	0.0	0.0	0.0
6/20/	0.0	0.0	4.0	0.0	0.0	0.0	0.0
6/21/	0.0	0.0	0.7	0.0	0.0	0.0	0.0
6/22/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/23/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/24/	0.0	0.0	0.0	10.1	1.2	0.0	0.0
6/25/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/26/	0.0	0.0	0.0	1.0	0.0	0.0	21.3
6/27/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/28/	1.0	0.0	0.0	0.0	0.0	0.0	0.0
6/29/	0.0	0.0	0.0	0.0	0.0	0.0	0.5
6/30/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/1/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/2/	0.0	0.0	0.0	0.0	0.0	0.0	9.0
7/3/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/4/	3.5	0.0	0.0	0.0	0.0	0.0	0.0
7/5/	1.2	0.0	0.0	0.1	0.0	0.0	0.0
7/6/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/7/	0.0	0.0	0.0	0.0	0.0	0.0	5.0
7/8/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/9/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/10/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/11/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/12/	0.0	0.0	0.0	0.0	0.0	0.0	0.0

7/13/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/14/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/15/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/16/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/17/	0.0	0.0	0.9	0.0	0.0	0.0	0.0
7/18/	0.0	0.0	3.5	0.0	0.0	0.0	16.0
7/19/	0.0	0.0	0.7	0.0	0.0	0.0	0.0
7/20/	0.0	0.0	0.0	0.0	0.0	0.0	0.8
7/21/	0.0	2.0	0.0	6.2	0.0	2.5	0.0
7/22/	0.0	2.5	6.8	0.0	0.0	0.0	0.0
7/23/	0.0	0.0	0.0	0.0	0.0	0.0	1.5
7/24/	0.0	0.0	0.0	0.0	0.0	1.6	4.4
7/25/	0.0	0.0	0.0	0.0	0.0	3.6	0.0
7/26/	8.0	1.1	0.0	0.0	0.0	0.7	0.0
7/27/	0.0	0.0	1.7	0.0	0.0	0.0	2.4
7/28/	0.0	0.0	0.0	0.0	0.0	0.5	7.5
7/29/	1.4	0.0	0.0	0.0	0.0	0.0	0.0
7/30/	0.0	28.7	0.0	0.0	0.0	0.6	0.0
7/31/	0.0	1.5	0.0	0.0	0.0	2.8	0.0
8/1/	0.0	24.7	0.0	0.0	0.0	0.0	0.0
8/2/	0.0	0.1	0.0	0.5	0.0	0.0	0.0
8/3/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8/4/	0.0	0.0	2.8	15.5	0.0	0.0	0.0
8/5/	0.0	0.0	0.0	0.1	0.0	0.0	0.0
8/6/	0.0	0.0	0.0	0.1	0.0	0.0	0.0
8/7/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8/8/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8/9/	0.0	0.0	0.0	0.0	0.0	0.0	0.0

8/10/	0.0	0.7	0.0	0.0	0.0	0.0	3.5
8/11/	0.0	12.5	0.0	0.0	0.0	0.0	12.0
8/12/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8/13/	12.2	0.0	0.0	0.0	0.0	0.0	20.2
8/14/	0.5	0.0	0.0	0.0	0.0	0.0	3.5
8/15/	9.7	0.0	0.0	0.0	0.0	0.0	16.2
8/16/	5.4	0.0	0.0	0.0	0.0	0.0	0.0
8/17/	40.7	0.0	6.2	0.0	0.0	2.5	0.0
8/18/	5.1	3.7	8.0	0.0	0.0	0.0	0.0
8/19/	0.5	0.0	0.0	0.0	0.0	0.0	0.0
8/20/	11.7	0.0	0.0	0.0	0.0	4.6	0.0
8/21/	0.8	0.0	15.4	0.0	0.0	5.5	0.0
8/22/	0.0	0.0	0.0	17.5	0.0	0.5	0.0
8/23/	0.0	0.0	5.3	0.0	0.0	0.0	0.0
8/24/	0.0	0.0	0.0	0.0	0.0	17.2	3.7
8/25/	0.6	0.0	0.0	0.1	0.0	8.2	32.1
8/26/	11.0	0.0	0.0	14.0	0.0	0.0	5.4
8/27/	13.5	0.0	0.0	21.2	0.0	0.0	0.0
8/28/	0.0	0.0	0.0	0.0	0.0	2.0	0.0
8/29/	0.0	0.0	0.0	0.0	0.0	1.6	0.0
8/30/	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8/31/	0.0	0.0	0.0	0.0	3.5	0.0	0.0
9/1/	0.0	0.0	0.0		0.0	0.0	4.2
9/2/	0.0	0.0	0.0		0.0	0.0	5.1
9/3/	0.0	0.1	0.0		0.0	1.3	32.0
9/4/	0.0	1.2	0.0		0.0	0.0	17.2
9/5/	0.0	1.4	0.0		0.0	0.0	40.9
9/6/	0.0	0.0	52.4		0.0	0.0	0.0

9/7/	0.0	0.0	0.0
9/8/	0.0	0.0	6.3
9/9/	2.5	0.0	2.8
9/10/	0.1	0.0	0.0
9/11/	0.0	0.0	0.0
9/12/	0.0	0.0	15.4
9/13/	0.0	0.0	10.0
9/14/	0.0	4.4	8.8
9/15/	0.0	0.0	14.6
9/16/	0.0	0.0	2.4
9/17/	0.0	0.0	0.8
9/18/	0.0	0.0	0.0
9/19/	0.0	1.2	0.0
9/20/	0.0	0.0	0.0
9/21/	0.0	0.0	0.0
9/22/	0.0	0.0	0.0
9/23/	0.0	0.0	0.0
9/24/	0.0	0.0	0.0
9/25/	0.0	0.0	0.0
9/26/	0.0	0.0	0.0
9/27/	0.0	0.0	0.0
9/28/	0.0	1.6	0.0
9/29/	0.0	2.7	0.0
9/30/	0.0	0.0	0.0
10/1/	0.0	1.5	0.0
10/2/	0.0	1.6	13.5
10/3/	6.2	0.0	22.0
10/4/	0.0	0.0	4.3

0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	3.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	4.8	0.0
0.0	0.0	0.0
4.5	3.6	0.0
9.6	7.6	0.0
1.1	0.0	0.0
5.1	9.4	0.0
6.2	0.0	0.0
0.6	0.0	0.0
2.1	0.0	0.0
2.7	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
15.5	0.0	0.0
0.0	0.0	19.5
7.3	0.0	0.0
0.0	3.3	0.0
8.0	13.3	2.2
15.5	2.2	0.0

10/5/	0.0	0.0	1.3
10/6/	0.0	0.0	0.0
10/7/	0.0	0.0	0.0
10/8/	2.4	0.0	0.0
10/9/	0.0	0.0	0.0
10/10/	0.0	0.0	0.0
10/11/	0.7	0.0	0.0
10/12/	1.5	0.0	7.0
10/13/	4.8	0.1	22.7
10/14/	0.0	3.2	0.0
10/15/	13.7	0.0	0.0
10/16/	9.0	0.0	0.0
10/17/	1.0	0.0	4.6
10/18/	0.0	1.2	4.8
10/19/	0.0	6.5	0.0
10/20/	0.0	0.5	0.0
10/21/	0.7	2.4	0.0
10/22/	0.0	8.0	4.7
10/23/	2.5	1.8	0.0
10/24/	21.0	7.5	30.5
10/25/	0.1	5.4	0.0
10/26/	0.8	2.5	7.5
10/27/	2.7	10.0	0.0
10/28/	1.4	8.0	0.0
10/29/	0.0	0.0	0.0
10/30/	0.1	0.0	0.0
10/31/	4.2	0.0	0.0
11/1/	0.0	8.5	0.0

2.7	0.0	0.0
1.1	0.5	25.0
0.0	0.7	0.0
0.0	0.0	0.0
0.4	0.0	0.0
0.0	4.0	0.0
0.0	0.0	3.3
0.0	1.3	0.0
0.0	4.3	9.0
0.4	2.2	1.9
16.6	5.8	0.5
17.2	0.0	0.0
0.0	0.0	18.4
25.7	0.0	3.8
0.0	0.0	0.5
0.0	5.7	18.7
0.0	3.1	9.0
0.0	2.3	0.0
0.0	0.6	0.0
0.0	0.0	2.4
0.0	2.0	0.0
0.0	4.2	0.0
0.0	0.0	20.5
11.5	0.0	14.8
3.5	0.0	0.0
3.3	0.0	0.0
0.0	0.0	0.0
1.6	1.5	0.0

11/2/	16.4	2.2	3.8	12.3	0.0	5.8
11/3/	1.1	0.0	0.7	2.2	2.8	0.0
11/4/	1.1	0.0	1.7	3.4	0.5	0.0
11/5/	0.5	0.0	3.8	0.0	5.8	0.0
11/6/	35.0	0.0	8.3	0.0	3.3	0.0
11/7/	0.1	14.0	0.0	0.0	3.5	0.0
11/8/	0.1	4.6	0.0	0.0	0.5	0.0
11/9/	0.0	0.0	0.0	0.0	24.3	7.2
11/10/	0.0	9.9	0.8	0.0	3.3	0.0
11/11/	13.2	19.3	9.7	0.0	0.0	0.0
11/12/	1.8	8.5	0.0	0.0	5.4	1.0
11/13/	1.8	15.2	0.9	0.0	0.0	30.2
11/14/	1.0	0.0	12.7	0.0	14.9	0.0
11/15/	3.2	11.6	12.5	1.6	0.0	0.0
11/16/	0.8	2.3	1.7	1.7	0.0	2.4
11/17/	0.0	4.2	0.0	0.0	0.0	0.0
11/18/	3.4	2.0	0.0	0.0	10.2	16.7
11/19/	0.5	1.8	0.0	0.0	0.0	6.0
11/20/	13.0	0.0	0.0	0.0	0.0	0.0
11/21/	2.3	0.6	0.0	0.0	0.0	0.0
11/22/	6.5	3.5	0.0	16.7	0.0	0.0
11/23/	8.2	0.0	7.4	0.0	0.0	0.0
11/24/	31.0	0.0	9.2	0.5	2.7	2.6
11/25/	0.7	6.2	2.1	0.0	0.0	57.7
11/26/	17.8	2.6	3.0	0.0	0.8	10.5
11/27/	1.9	0.0	18.8	0.7	0.0	4.5
11/28/	1.0	0.0	0.0	0.0	1.8	3.4
11/29/	3.2	0.0	2.0	22.0	0.7	0.0

11/30/	15.0	5.4	0.0	0.0	0.0	6.1
12/1/	1.6	0.7	0.0	0.0	0.0	0.0
12/2/	0.6	0.0	0.9	5.6	0.0	30.3
12/3/	12.5	0.0	0.0	9.8	0.0	3.3
12/4/	3.7	11.7	0.0	5.7	0.0	7.4
12/5/	2.0	0.0	0.0	0.0	0.0	0.0
12/6/	0.1	0.0	0.0	0.0	0.0	0.0
12/7/	0.0	0.0	0.0	0.0	3.4	0.0
12/8/	6.0	24.4	51.7	0.0	2.5	0.0
12/9/	4.0	0.6	1.0	5.5	0.0	0.0
12/10/	0.0	2.2	2.2	4.1	0.5	0.0
12/11/	0.0	2.3	0.0	0.0	0.0	0.0
12/12/	0.0	5.6	0.0	1.4	1.6	0.0
12/13/	0.0	0.0	0.0	2.9	0.0	0.0
12/14/	0.0	0.0	0.0	0.0	0.0	0.0
12/15/	0.0	0.0	0.0	0.0	0.0	0.0
12/16/	0.0	0.0	1.6	0.0	0.0	0.0
12/17/	0.0	0.0	0.0	0.0	0.0	0.0
12/18/	0.0	0.0	0.0	0.0	0.0	0.0
12/19/	0.1	0.0	0.0	0.0	0.0	0.0
12/20/	2.8	0.0	0.0	3.2	0.0	0.0
12/21/	1.5	4.4	0.0	0.0	0.0	0.0
12/22/	0.0	0.0	0.0	0.0	0.0	0.0
12/23/	0.0	0.0	0.0	35.1	0.0	0.0
12/24/	0.0	0.1	0.0	6.5	0.0	0.0
12/25/	0.0	0.0	0.0	4.8	0.0	0.0
12/26/	0.0	0.0	0.0	3.5	8.4	0.0
12/27/	0.0	0.0	0.0	0.0	0.0	0.0

12/28/	0.0	0.0	0.0
12/29/	0.0	0.0	0.0
12/30/	0.1	0.0	0.0
12/31/	5.4	0.0	0.0

18.1	1.0	0.0
19.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0

Appendix 4 Pan evaporation (mm) data for Matanya Met. Station: 2009-2010

MONTH	2009	2010	2011
JAN	152	224	291
FEB	157	204	308
MAR	304	236	281
APR	262	204	259
MAY	246	220	287
JUN	329	244	288
JUL	361	308	254
AUG	367	265	259
SEP	328	225	306
OCT	246	243	239
NOV	220	166	198
DEC	175	250	236

Appendix 5- Chi-square test on adoption of water pans in the study area.

Category	Observed (O)	Expected (E)	O-E	(O-E) ²	(O-E) ² /E
With RWH	11	6.6	4.4	19.6	2.9
Without RWH	11	15.4	-4.4	19.6	1.3

$$X^2=4.2$$

Appendix 6 Crop Production Statistics for Laikipia Central

Crop	2006		2007		2008		2009		2010		2011	
	Ha	Bags or Tons	Ha	Bags Or Tons	Ha	Bags or Tons	Ha	Bags or Tons	Ha	Bags or Tons	Ha	*Bags or Tons
Sorghum	-	-	35	7	47	2	90	9	71	7	25	17
f.millet	-	-	10	8	4.5	4	0		0			
P. peas	-	-	8.5	3.5	10.6	1	6	6	14	7	30	8
wheat	255		2422	16.5	2600	2.3	750	14	1420	3.5	1800	18
maize	1500	5	2600	13	2470	2.5	1650	13	2400	8	2700	16
beans	1196	1	1666	5	2400	0.2	1060	15	1450	2.8	2000	0.9
i.potatoes	1427	3T	1360	9 T	1220	0.3 T	300	7 T	1040	7 T	1450	0.8
s.potatoes	-	-	5.5	20 T	4.8	4.8 T	3	10 T	5.5	6.4 T	3	15T
dolichos	-	-	9	10	20	4	10	10	17	8	14	6
G.peas	51	1T	110	6.4 T	150	0.5 T	40	6 T	40	6 T	78.5	T
tomatoes	63	30T	100	20 T	58	2 T	10	15 T	150	15 T	40	9T
cabbages	35	40T	45	21 T	50	10 T	35	15 T	35	15 T	60	10T
kales			17	5 T	25	2 T	-	-	-	-	9	8T
French beans	90	8T	65	6.4 T	95	5 T	50	5 T	50	5 T	75	4T

Source: Annual reports DAO Laikipia East and Laikipia Central *Forecasted in December, 2011.