FACTORS INFLUENCING CHOICE OF IRRIGATION SYSTEMS AND CROP WATER REQUIREMENT OF HIGH VALUE CROPS IN MWALA, MACHAKOS COUNTY, KENYA

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A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science in Land and Water Management in the Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented for the award of a degree in any other academic institution.

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DEDICATION

To my dear mother and siblings for their immense support towards my studies, may the light of our Lord’s countenance shine upon you always.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADS</td>
<td>Anglican Development Services</td>
</tr>
<tr>
<td>ASALs</td>
<td>Arid and Semi-arid Lands</td>
</tr>
<tr>
<td>CIDP</td>
<td>County Integrated Development Plan</td>
</tr>
<tr>
<td>CWR</td>
<td>Crop Water Requirement</td>
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<tr>
<td>ET</td>
<td>Evapotranspiration</td>
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<tr>
<td>FAO</td>
<td>Food and Agricultural Organization</td>
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<tr>
<td>MWI</td>
<td>Ministry of Water and Irrigation</td>
</tr>
<tr>
<td>NIR</td>
<td>Net Irrigation Requirement</td>
</tr>
<tr>
<td>PET</td>
<td>Potential Evapotranspiration</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for Social Sciences</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Program</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
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<tr>
<td>WRSI</td>
<td>Water Requirement Satisfaction Index</td>
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GENERAL ABSTRACT

Selecting the best-suited irrigation system for a specific site considers a number of factors. These include initial and operating costs, labor and energy requirement, adaptability to farming operations, soil, climate and personal preference among others. A study was carried out mainly with a goal to assess the factors influencing the choice of irrigation technology and crop water requirement of high-value crops using the FAO CROPWAT model in Mwala Sub County, Machakos County. Specifically, the research sought to characterize irrigation methods practiced in Mwala, and factors influencing the choice and adoption of irrigation, to assess factors affecting farmers’ decisions on timing and application rates of irrigation water, and to determine the crop water requirement of most commonly grown high value crops in Mwala using the FAO CROPWAT model. A survey was conducted using the questionnaire-by-interview method and field experiments were done to obtain data on the factors influencing choice, operation and adoption of irrigation technology. Crop data for the FAO CROPWAT model was collected both directly from the field and from the questionnaire. Soil samples were also collected and analysed in the laboratory and climate data obtained from Kathumani meteorological station for the soil and climate data required by the model. The respondents of the questionnaire comprised of purposefully selected farmers registered under the Equity Group Foundation extension scheme. Amongst these were 82 farmers, 41 of which practiced supplemental irrigation and 41 practiced purely rain-fed agriculture. From the findings, it was revealed that irrigating farmers used drip, sprinkler, furrow and hosepipe irrigation methods. The results too revealed that farmers perceived pumped systems like drip, and sprinkler to cost more in terms of maintenance and installation expenses; they were also less difficult to use and required less labor and energy when compared to the other systems like hosepipe, furrow, and basin irrigation.
Irrigating farmers also perceived these two irrigation systems to perform better in terms of application efficiency followed by, furrow, use of hosepipe and basin respectively. Due to this, 85% of the farmers preferred drip irrigation, 9% preferred sprinkler and 6% preferred furrow irrigation. Important factors in purchasing irrigation systems to farmers were water delivery efficiency, labor requirements and maintenance expenses. The farmers identified soil conditions, plant conditions, recent temperature, recent rainfalls and days since last irrigation as the most important factors in deciding the amount and timing of water application on crops. Regression analyses done on the demographic factors indicated that there were significant differences (p<0.05) between irrigating and non-irrigating farmers with respect to the gender and age of the respondents, their total farm acreage and number of hired farm workers, and approximate annual household income (p<0.001). It was also revealed that there was no significant difference (p<0.05) between irrigated and non-irrigated farming on the education level, farming experience, training on irrigation and farm management systems. The study also revealed that the major crops grown in the study area were maize (Zea mays), tomatoes (Solanum lycopersicum), french beans (Phaseolus vulgaris), vegetables (such as Brassica oleraceae, Solanum villosum), bananas (Musa acuminata and Musa balbisiana), mangoes (Mangifera indica) and oranges (Citrus sinensis). The crops consumed higher amounts of water during the dry season than during the rainy season. The crop evapotranspiration (ETc) and the crops’ irrigation requirements for the crops were estimated whereby; maize had the lowest ETc at 180 mm while bananas had the highest at 277 mm during the rainy season. Additionally, maize had the lowest ETc at 201 mm and bananas had the highest ETc at 314 mm within the dry season.
The highest total irrigation water requirement was recorded in bananas at 1216 mm during the rainy season and 1740 mm during the dry season while the lowest was recorded in french beans at 178 mm during the rainy season and 529 mm during the dry season. When the irrigation requirements were compared to the actual amount of water applied to the crops, it was revealed that the applied water exceeded the irrigation requirements. Mangoes and oranges exhibited the largest average difference between applied water and IR per day; and this was 75 mm and 64 mm respectively, and the least in bananas, 3 mm. The implication of these findings is that costs and water delivery efficiency are the most important to farmers in choice and adoption of irrigation technology. The capital requirement for acquisition of preferred irrigation systems like drip and sprinkler can be enhanced using targeted credit programs by formal financial institutions in addition to Equity Group Foundation to ameliorate the financial constraint. It is too suggested that availability of water adequately and at the required time in addition to assisting non-irrigating farmers gain access water will improve adoption and effective application of irrigation water. The findings also reveal the need for more on-farm training on efficient irrigation practice that can enhance skills of farmers on appropriate irrigation practice.

**Keywords:** Choice of irrigation technology, crop water requirement, crop evapotranspiration, irrigation scheduling.
CHAPTER ONE: INTRODUCTION

1.1 Background Information

Sub-Saharan Africa continues to face chronic food insecurity as 80–95% of agriculture is rain-fed (Boon, 2015). This necessitates the need for irrigation to provide Africa’s fast and ever-growing population with adequate food (Perlman, 2016). The continent experiences erratic and highly variable rainfall thus creating uncertainty for agricultural production further emphasizing the need for irrigation (Adeoti, 2009).

The use of irrigation can increase the amount of water available for crop production in the arid and semiarid regions of Africa (Kohpahie et al., 2003). Agriculture can be enhanced by use of appropriate irrigation technologies and adequate water management (Adeoti, 2009). Farmers can ensure adequate water management by either maintaining or reducing water use on their farms without any negative impact on crop yields and profit (Enciso et al., 2015). In irrigated farming particularly where water is scarce, water use efficiency can be improved so farmers can fully benefit from other production inputs such as fertilizers, high-quality seeds, labor, energy and machinery among others (Sharma et al., 2015).

Different irrigation methods exhibit diverse features, which can make them best suited for a specific case, depending on how it has been designed, installed, operated and maintained (Karami, 2006). Proper designing, installation, operation and maintenance of any irrigation method can enable it to give desired results in crop production. It is thus important that a farmer assess the pros and cons of the various irrigation methods before coming to a decision to which one best suits the local conditions (Valipour, 2013).
Various studies show that different factors such as social, economic and physical factors influence the choice of irrigation technologies by farmers (Saeed et al., 2014). Social factors such as the farmer’s education level, provision of extension services and availability of labor significantly affect a farmer’s decision to adopt an irrigation method (Adeoti, 2009). According to Oka (2000), economic factors, such as access to credit, are also very effective elements influencing the farmers’ choice of irrigation systems. Irrigation investments ought to be fully recoverable as the revenue should equal the cost for one to achieve efficiency (Ali, 2010). Some of the factors that affect the benefits from irrigated agriculture include high input costs, low crop prices and reduced crop yields (Ali, 2010).

Physical factors influencing the choice of irrigation systems include crops to be cultivated, nature of land, the soil type, soil water content, climate and energy sources (Wang et al., 2013).

Farmers practicing irrigation need to have sufficient information on irrigation scheduling (Lamm and Rogers, 2015). This is very critical in determining the time and depth of water application for each irrigation event (Broner, 2005). Plants require water of adequate quantity and good quality for vegetative growth and development. This water should be available within the plant rhizosphere in appropriate quantity and at the right time (O’leary et al., 2015). Poor irrigation scheduling is common among the sub-Saharan Africa farmers resulting in inefficient use of water (Grant et al., 2012). For proper irrigation scheduling, knowledge of crop water requirement is essential (Morillo, 2015).
Crop water requirement gives the depth of water that is required to recover the water that is lost through evapotranspiration (ET) of a disease free crop (Mehta, 2015). The crop has to be growing in a field exhibiting non-restricted soil conditions such as soil moisture content and fertility, as well as be able to achieve its full potential in production of yield under the given growing conditions (Zhuo et al., 2014). Various models have been used to simulate crop water requirements for crops. For instance, the CROPWAT 8.0 model enables one to calculate the crop water and irrigation requirements using data on the given soils, climate and crops (Naik et al., 2015). It also allows for the development of irrigation schedules for calculation of scheme water supply for varying crop patterns (Smith et al., 2002). Another example of a model used to estimate the irrigation water need is the BISm model (Snyder et al., 2004). This model requires inputs of the planting and harvesting dates, total water holding capacity and available water content of the soil. The model uses these inputs to calculate the crop coefficients (kc) accounting for the depletion of water from crop root zone (Snyder et al., 2004).

The crop water requirements vary for different crops, and this depends on the local climatic conditions (Ye et al., 2015). Despite their high soil water requirement, the major common crops produced by farmers in semi-arid areas of Kenya include maize, tomatoes, bananas, french beans, cassava, pigeon peas and sweet potatoes (ADS Eastern Secure Livelihoods, 2017: Omoyo et al., 2015). In Machakos, farmers are adopting supplemental irrigation farming to enhance the production of staple crops, fruits and tree crops (Barron, 2004).

The practice has contributed to increased crop yields due to the reliability of water supply provided by irrigation and reduced variation and uncertainty per acre of irrigated farms (Adeoti, 2009). Besides, this strategy has resulted in an increase in the total acreage of lands under agriculture (UNDP, 2017).
1.2 Statement of the problem

Despite its rising population density, Machakos County remains food insecure; a fact attributed mainly to the low and erratic rainfall received in this area (ADS Eastern Secure Livelihoods, 2017). According to Goita et al. (2013), the current food insecurity situation in Machakos is also caused by other factors including frequent droughts and increased cost of agricultural inputs. Supplemental irrigation has the potential to increase agricultural production and productivity and this mainly relies on water availability (Mueller and Binder., 2015).

The decision to adopt a given irrigation technology depends on a number of key parameters, including area of land, topography, soils, water supply, climate, crops and finances among others (Smith et al., 2016). To choose appropriate irrigation method, the farmer needs to have sufficient information about the advantages and disadvantages of the various methods (Harrison, 2009).

Though most farmers solely consider economic viability of the irrigation systems as the basis of selecting the irrigation method, this strategy may not be appropriate (Karami, 2006). Considering as many of the relevant criteria as possible in the selection process of irrigation system is necessary for enhanced efficiency and effectiveness of the system. Choosing the right system can enable one to offset the cost of installation and operation of the system (Evans and Sadler, 2008). A suitable and effective irrigation system is also able to allow for adequate water management due to efficient water use particularly where water is scarce (Adeoti, 2009; Sharma, 2015).

Meeting the crop water requirement is very critical as it enables the crop to recover the water that is lost by evapotranspiration, thus providing the quantity of water required a crop to grow optimally (Passioura and Angus, 2010). The crop performance is reduced if inadequate amount of water is stored in the crop root zone of most of the irrigated area (Condon et al., 2002). Effective irrigation therefore involves adequacy and uniformity in its application (Howell, 2001).
1.3 Justification

Assessing the factors determining the choice of irrigation systems will ensure efficient water use and better public understanding of the various irrigation technologies. Determining the crop water requirement of some of the high value crops grown in semi-arid areas of Kenya is essential in improving the crop performance. This is because effective irrigation ensures crops get optimal water for growth resulting in increased crop productivity.

Effective application of various irrigation technologies and their potential is essential for water conservation in Machakos County. This would be achieved by providing the pertinent information to help conserve water and thereby minimize potential wastage of water used for irrigation (Ngugi et al., 2015). Understanding the choice of irrigation systems by the farmers is important in the formulation of public policies and private strategies for the agricultural sector.

1.4 Objectives

Overall objective

To assess the factors influencing the choice of irrigation technology and crop water requirement of high value crops among farmers in Mwala, Machakos County for enhanced crop productivity.

Specific objectives

i. To characterize the various irrigation technologies practiced in Mwala, Machakos County and the factors influencing the choice and adoption of irrigation

ii. To assess the factors affecting the farmers’ decisions on timing and application rates of irrigation water

iii. To determine the crop water requirement of the most commonly grown high value crops using the FAO CROPWAT model.
1.5 Research questions

i. What are the various irrigation technologies practiced in Mwala, Machakos County and the factors influencing the choice of adoption?

ii. What are the factors influencing farmers’ decisions on timing and application rates of irrigation water?

iii. What are the crop water requirements of the most commonly grown high value crops in the study area?

1.6 Organization of the thesis

This thesis is presented in six chapters. Chapter 1 gives the background information of the research study and briefly describes the factors influencing the farmers’ choices of irrigation systems. It also defines crop water requirement and the necessity of its consideration in irrigated farming. It is in this chapter that the research problem, objectives, research questions and the justification of the study are too presented. The second chapter presents the literature review of the previous works done concerning this study. On the other hand, chapter three, four and five give abstracts, brief introductions, materials and methods and the results and discussions of each of the three objectives of the study. The last chapter (six) presents the summary of the study, conclusions and suggestions for further research.
CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

2.2 Demand for water in agriculture

Agriculture consumes the largest amounts of water in the world today and most of this water is lost through evapotranspiration (Barrow, 2016). Total evapotranspiration from global agricultural land is expected to double in next 50 years escalating trends of food consumption and practices of food production (Sharma et al., 2015). Improved agricultural water productivity is thus required to help meet the rising demands for food and even contribute to poverty reduction and economic growth of poor farmers (Molden et al., 2010). Ensuring high water productivity can too result in low costs of cultivation and also lower the energy required to withdraw water (Yihun et al., 2013).

Water is of critical importance among the inputs necessary for crop production as plants need water in large quantities continuously for growth and development (Claeys and Inzé, 2013). Water greatly influences a plant’s physiological processes like photosynthesis, respiration, absorption, translocation and utilization of mineral nutrients among others (Rao et al., 2016). This great need for water is not easily met by rainfall due to its uncertainty and high variability thus necessitating the use of irrigation water (Adeoti, 2009). For optimal development of crops, a balanced irrigation is essential to ensure efficient crop water use and to reduce water losses and wastage through seepage (Abdul-Ganiyu, 2015).
2.3 Factors affecting irrigation technology

Factors that greatly influence modern irrigation methods include: water availability, the type of exploitation, farming system, finance, marketing and the role of government and private-sector agencies (Adeoti, 2009). Individual and social factors and organizational support also attract farmers to adopt various irrigation methods (Wituk et al., 2002).

2.3.1 Economic factors

Studies have shown that economic factors are very effective in attracting farmers to adopt specific irrigation methods (Oka, 2000; Panahi, 2013). Saeed et al. (2014) found in Iran that economic factors such as average annual income from agriculture and average farm assets and non-farm assets were most considered by farmers in the choice of irrigation systems. Lack of a financial and credit system to pay and assist farmers and absence of strong financial ability are among the most important limitations that farmers face in selecting the most suitable irrigation system (Giordano, 2012).

Irrigation systems are chosen to maintain, increase crop yield or reduce uncertainty of yield or both (Matekole, 2003). Musch and Schmidt-Kallert (2000) carried out a study in Madagascar and Schuck et al. (2005) in Colorado found that changes on irrigation technology can allow producers to continue production on lower levels of water applications while still maintaining a high crop yield thus high returns from farming. According to Fang et al. (2014), limited amounts of irrigation water maintained high yield and water use efficiency at irrigation targets between vegetative and reproductive stages. Adopting water efficient irrigation technology is able to decrease percolation, seepage and evapotranspiration losses, besides better utilization of rainfall (Ali, 2010).
Thus, this increases the amount of water available for crop use as wastage of irrigation water is reduced. Schaible and Aillery (2012), carried out a study in the mid plains of the United States and also found out that transitions to a water conserving irrigation technology enhances both farm profitability and long-term irrigation sustainability.

Amossen et al. (2001) examined the economics of irrigation systems used in Texas. Amongst other issues, the study focused on the potential benefits of each system on improving water application efficiency and reduction of field operations. Results from their analysis showed that some irrigation systems like drip and sprinkler had higher application efficiency and exhibited reduced field operations. Carey and Zilberman (2002) adapted the option value theory to develop a stochastic dynamic model that was used to assess how water markets influenced farmland decisions on the adoption of improved water-saving irrigation technologies. Their analysis showed that farms with relatively abundant water supplies were likely to be early adopters of improved irrigation technology when water markets are introduced, whereas those with scarce water supplies would be late adopters.

Several studies show that farmers generally adopt irrigation technologies from which they are able to maximize profits and minimize their cost. Other economic factors include water prices, tax policies, pumping costs, land characteristics and water quota rates (Matekole, 2003).

### 2.3.2 Social and institutional factors

Social and institutional factors involve issues as water rights, taxation, financial incentives from governments and construction permits, among others (Anderies et al., 2004). These issues influence other factors like availability of equipment and support services, incentives from authorities, availability of labor, water right and water regulations, level of competence and literacy among others (Svendsen and Nott, 2000).
Individuals and groups of individuals normally must come together as a community to construct, operate and maintain an irrigation system as a whole. The community thus requires sufficient adaptability to change to new water conserving irrigation systems (Zhang et al., 2013). The community members form the major action team of the institutional and organizational arrangement. Features of the community members will thus influence their view on water conveyance and delivery properties which also affects their decisions on irrigation management (Wang et al., 2013).

Age, education and extension services are also very important factors that affect farmers’ attitudes towards the various irrigation systems. Membership in cooperative societies and high frequency of extension visits increase adoption of irrigation systems as this improves the adequacy of the information which can impact the adoption decision (Adeoti, 2009). Norozi and Chizari (2007) researched in Iran and from their findings they believed that farmers who are aware of educational and extensional classes are able to apply the obtained skill more than those deprived from the awareness of these systems. This has a significant effect on their level of acceptance to use various irrigation systems.

2.4 Crop water use

Different crops require varying quantities of water to grow and develop depending on the stage of growth (Evans and Sadler, 2008). Water use efficiency relates the yield from the crop to the amount of water transpired by the crop (Sadras et al., 2011). Irrigation efficiency, on the other hand, compares the amount of water lost through crop evapotranspiration, the water stored in the root zone and the yield to the amount of irrigation water application (Sharma et al., 2015).
One could desire to limit the amount of water a crop transpires in some cases like in deficit irrigation, especially when the objective of irrigation is not maximizing transpiration (Fairweather et al., 2003). Even so, a farmer should ensure crops are not stressed especially during critical growth periods for this reduces yield and quality of crops. Crop water use at these stages can thus be used in irrigation scheduling to avoid stressing crops (Al-Kaisi et al., 2009).

Quantification of irrigation water depth is very essential as water deficit or excess can negatively influence crop production. Water deficit lowers crop yield (Mani, 2014) and commercial productivity (Pires et al., 2013). Water excess too reduces the yield (Suassuna et al., 2011; Cavalcanti et al., 2015) and results in the loss of water and nutrients beyond the root zone (Pires et al., 2013, Figueirêdo et al., 2014), further escalating the costs of production. A study by Fairweather et al. (2003) showed that lowering irrigation application amounts below optimum results in a positive response in yield for each unit of water applied (the steep response curve A in Figure 2.1). In soils that are well drained, there is no further increase in yield beyond this optimum point (B in Figure 2.1) for each extra input of irrigation water.

However, when one applies more water than is necessary (between points B and C of Figure 2.1), this provides cheap insurance for a high value crop since irrigation takes a very small percentage of the input costs and also due to the uncertainty of the location of point B. Applying water at rates beyond point C reduces the yield which would then encourage application of less water. Thus, there is little financial incentive for lower water application amounts between the points B and C (Fairweather et al., 2003).
Crop water use efficiency gives the amount of transpired (or used) water that an individual crop converts to grain (Cribb et al., 2012). On the other hand, systems water use efficiency shows the rate at which rainfall is converted to grain over multiple crop and fallow phases (Evans, 2008).

### 2.4.1 Crop water and irrigation requirements

The crop water requirement gives the amount that is required to cover the fraction of water lost through evapotranspiration from a crop field (Ouda et al., 2016). Besides, irrigation requirement gives the quantity of water that must be supplied to crops throughout the growing season (Welbaum, 2015). Various models are used to calculate the crop water requirement of crops under irrigation. Some of these models include the FAO CROPWAT model, the crop water requirement satisfaction index (WRSI) (McNally et al., 2015) and the BSim model (Seidel et al., 2016).

The CROPWAT computer program is a decision support tool that calculates the crop water requirements and irrigation requirements using crop, soil and climate crop data (FAO Water, 2015). The program aids in the development of irrigation schedules for various management conditions and calculates the scheme water supply for different cropping patterns (Kuo et al., 2001).
CROPWAT 8.0 can too be used to assess irrigation practices and to evaluate crop performance under irrigated and non-irrigated conditions. Surendran et al. (2017) carried out a study in India and Bouraima et al. (2015) in Northern Benin using the model to estimate crop reference and actual evapotranspiration and the irrigation water requirement of crops and recommended their findings for use in irrigation projects.

The program involves standardized crop and soil data. Development of irrigation schedules in the model is based on a daily soil-water balance that utilizes various user-defined options for water supply and irrigation management conditions. The scheme water supply is calculated according to a user-defined cropping pattern that can include more than 10 crops (FAO Water Development and Management Unit, 2015).

**Climate data collection**

The reference evapotranspiration ($ET_0$) characterizes the potential evapotranspiration of a grass crop that is watered well. Crop water needs of other crops are thus linked directly to this climatic parameter. The Penman-Monteith Method is the one recommended as the most suitable combination method to determine $ET_0$ from climatic data on: sunshine, temperature, wind speed and humidity. For one to calculate this, respective climatic data is collected from the nearest and most representative meteorological station (FAO Water Development and Management Unit, 2015).

The collected climate data by the national meteorological service is then standardized. For some, conversions are required so as to adjust the data into a format that can be accepted by CROPWAT 8.0.
Some of the conversions to units required for CROPWAT 8.0 include:

**Temperature data**

IMS: Mean Daily Maximum and Minimum Temperature (°C)

CROPWAT: Maximum and Minimum Temperature (°C)

Conversion: No conversion needed

**Humidity data**

IMS: Relative Humidity (in percentage) as well as the Vapour Pressure (kPa) both for morning and afternoon

CROPWAT: Average daily Relative Humidity (in percentage) as well as the Vapour Pressure (kPa) both for

Conversion: Average of morning and afternoon values of vapour pressure

Comments: Vapour Pressure rather than Relative Humidity values are taken, as the latter relate to temperature values at sunrise and noon

**Sunshine data**

IMS: Cloudiness in Oktas of sky of All and Low Clouds for morning and noon

CROPWAT: Sunshine hours (heliograph) or sunshine percentage

Conversion: According to the following relationship (Equation 2.1):

\[
SSP = 0.95 - \frac{LC1 + LC2}{2} + \alpha \frac{AC1 + AC2}{2}
\]

Equation 2.1
Where: $SSP =$ sunshine rate (fraction), $LC1 =$ low clouds at sunrise (oktas), $LC2 =$ low clouds at noon (oktas), $AC1 =$ high clouds at sunrise (oktas), $AC2 =$ low clouds at noon (oktas), $\alpha =$ empirical parameter (= 0.3)

**Wind speed data**

IMS: Average Daily Windrun in km/hr

CROPWAT: Average Daily Wind speed in km/day or m/sec

Conversion: $WS \text{ km/day} = 24 \times WS \text{ km/hour}$

**Rainfall data collection**

Rainfall can play a major or minor role in meeting the crop water need, depending on the locality of the farm. In tropical and semi tropical regions for instance, a great part of the crop’s water requirement is covered by rainfall during the wet season, while irrigation supplies most of the water during the dry season (Naheed and Mahmood, 2010; Tibebe, 2015). Statistical analysis on longterm records on rainfall can help estimate the rainfall deficit for irrigation water requirements. Precipitation data required for CROPWAT 8.0 can be daily, decade or monthly rainfall, which are usually accessible from many meteorological stations. Records of rainfall from a range between 15- 30 years are collected to enable calculation of rainfall probabilities (FAO Water, 2015).

**Crop and cropping pattern information**

This information is obtained by assessment of the different crops that are currently grown under irrigation and those that can be possibly grown in future. Information on various crop characteristics such as the rooting depth, length of development cycle and other crop factors also is obtained. Statistics on soil data is obtained by soil surveys (Surendran et al., 2017).
Irrigation scheduling

The CROPWAT 8.0 has an irrigation scheduling module that is a very important element which consists of several application options. These include:

- Development of indicative irrigation schedules
- Evaluation of existing irrigation practices on water use efficiency and water stress conditions;
- Evaluation of crop production under rain-fed conditions,
- Assessment of the feasibility of supplementary irrigation
- Development of appropriate irrigation schedules and;
- Development of alternative water delivery schedules under restricted water supply conditions.

The calculations of this scheduling module are based on a soil water budget whereby soil moisture status is determined on a daily basis accounting for the water getting into and leaving the crop root zone (Bouraima et al., 2015).

2.5 Irrigation water management

Research on water management has shown that uniformity of water distribution, quantity of water applied, number of irrigations, irrigation frequency and water availability impact crop yields. Additionally, optimal water use and application would vary depending on the irrigation system, crop type and soil characteristics. Lastly, farmers would maximize profits considering water and land availability. For instance, Panigrahi et al. (2001) investigated potato tuber yield water use efficiency for irrigation scheduling and plant furrow treatments under deficit water supply conditions. They discovered that water use efficiency at different irrigation levels had little impact on potato tuber yield.
However, plant furrow irrigation had a positive impact on yield. Additionally, the best yield obtained under furrow irrigation was as a result of maximum foliage coverage from higher amounts of crop evapotranspiration.

Reca et al. (2001) demonstrated the suitability of non-linear optimization techniques for water allocation planning in drought conditions in southern Spain. Research analysis showed that consideration of only the internal demands of the irrigating areas caused lower irrigation efficiency and high volumes of water allocations, which had low economic benefits per unit of water used.

Pereira et al. (2002) also examined irrigation management under water scarcity conditions. They realized that uniform application of irrigation water was especially important in areas where water quality was low, because it enhances efficiency of water application with less negative effects on the environment. Furthermore, the authors realized it was more profitable to optimize return per unit of water than land in water scarce areas. They also showed that maximization of return per unit of water was influenced by level of fertilizer applications on farms, sowing dates, and amount of rainfall.
CHAPTER THREE: FACTORS INFLUENCING CHOICE OF IRRIGATION SYSTEMS IN MWALA, MACHAKOS COUNTY, KENYA

Abstract
Irrigation is necessary to supplement rainfed agriculture and to improve agricultural yields in arid and semi-arid areas of Kenya. This study characterized the various irrigation systems practiced in a semi-arid area of Kenya and assessed the factors influencing choice of the irrigation systems by farmers in Mwala. A structured questionnaire was administered to 82 purposefully selected farmers registered under the Equity Group Foundation extension scheme. Forty-one (41) of the farmers were practicing supplemental irrigation and 41 purely practiced rain-fed farming. The results showed drip, furrow, sprinkler, use of hosepipe and basin as the main irrigation methods. Amongst these, 44% of the farmers used furrow irrigation on their crops, 10% used hosepipe, 17% used drip, 29% used sprinkler but none used basin irrigation in the 2015-2016 growing season. Factors influencing farmers’ decisions on adopting irrigation systems were assessed and the results revealed that 97% of the farmers perceived drip and sprinkler systems to be the most expensive to install and maintain. Use of hosepipe for irrigation (54%) was perceived to be the most difficult to use followed by basin (33%), drip (13%), furrow (7%) and sprinkler (4%). In labor and energy requirement, drip (36%) and sprinkler (33%) required the least labor followed by furrow (12%) and hosepipe (8%). Farmers rated basin and use of hosepipe to exhibit the lowest application efficiency with 85% of them rating basin to be the lowest, then use of hosepipe by 83%, furrow, 82%, sprinkler, 12% and drip 6%. A regression analysis done to establish the effect of interactions amongst the demographic characteristics indicated that there were significant differences (p<0.05) between irrigating and non-irrigating farmers with respect to gender and age of respondents, their total farm acreage and number of hired farm workers, and approximate annual household income (p<0.001).
These results clearly reveal that ownership capital, labor and energy requirement, application efficiency and ease of use are important factors in the farmers’ choice of irrigation systems. The findings show that there is need for more on-farm training on efficient irrigation practice to improve the skills of farmers. Enhancing financial support from targeted credit programs is also critical to ameliorate the capital requirement for acquisition of the more efficient drip and sprinkler systems.

**Key words:** Irrigation technologies, irrigation choice, farmers, Income levels
3.1 Introduction

Irrigation development has the potential to increase crop yield by increasing the amount of water available for crop production (Kohpahie et al., 2003, Panahi, 2013). This is especially in arid and semi-arid lands (ASALs) that are characterized by shortage of rainfall, hot and dry climate and drought (Mwasi, 2015). In Kenya, the ASALs form about 89% of the total land mass (Gulma et al., 2014).

The irrigation sector in Kenya is divided into smallholder schemes, private commercial schemes and centrally managed public schemes. Smallholder irrigation schemes cover a total land area of about 47,000 ha that is equivalent to 42% of the total area under irrigation. Centrally managed schemes, on the other hand cover an area of 18,200 ha accounting for 18% of irrigated land, while the large-scale private commercial schemes cover 45,000 ha that makes 40% of the irrigated land (Republic of Kenya, MWI, 2009).

Machakos County forms part of the semi-arid lands in Kenya experiencing erratic and unpredictable rainfall ranging between 500 mm and 900 mm per year (ADS Eastern Secure Livelihoods, 2017). The County predominantly exhibits smallholder irrigation schemes that are owned and managed by individuals and groups of farmers that operate as water users and self-help groups (Machakos CIDP, 2015). This is mostly done by farmers living near water sources such as Athi, Tana, and Thika rivers and the Yatta and Kayatta canals. The larger numbers of farmers that do not live near the water sources depend mainly on the unpredictable rain-fed agriculture predisposing them to food insecurity and low economic returns (Mburu et al., 2015). The county has three major irrigation schemes namely Kabaa, Yatta and Kayatta that have been proposed for expansion so as to increase food production (Machakos CIDP, 2015).
Different irrigation methods exhibit different features that can make them best suited for a specific case, depending on how it has been designed, installed, operated and maintained (Karami, 2006). These methods include surface systems such as basin, border and furrow methods. Basin method is based on the rapid application of irrigation water to a level area enclosed by embankment that retains the water at uniform depth until it infiltrates into the soil. Furrow irrigation on the other hand consists of application of water to a field by means of small, narrow field channels while border involves provision of parallel earth bunds or levees that guide an advancing sheet of water down the slope (Singh and Sharma, 2008).

A well-designed irrigation system if properly operated and maintained can enhance crop productivity in areas with soil moisture deficit. It is therefore important for proper assessment of the cons and pros of the various irrigation methods before deciding on which method best suits the local conditions (Valipour, 2013). The pressurized systems include sprinkler and drip irrigation methods. In sprinkler systems, water is sprayed into the air through sprinkler nozzle and allowed to uniformly fall onto the surface in a pattern resembling rain. Drip irrigation, on the other hand, involves water being supplied through plastic pipes that feed drippers (Singh and Sharma, 2008). Use of hosepipes is a traditional method of watering in which a hosepipe is fitted into a risomatic stand on gravity-pressured pipes. It involves watering by hand using a hosepipe which makes it possible to judge whether or not a plant needs water and how much (Merrey and Sally, 2008).

Various studies show that social, economic and physical factors influence the choice of irrigation technologies by farmers (Saeed et al., 2014). Social factors include farmers’ education level, provision of extension services and availability of labor (Adeoti, 2009).
Physical factors include the choice of crops to be cultivated, nature of land, soil type, soil moisture content, climate and energy sources (Wang et al., 2013).

According to Oka (2000), economic factors such as access to credit and credit facilities also influence the farmers’ choice of irrigation systems. Irrigation investments ought to be fully recoverable to achieve efficiency. This implies revenue obtained from an irrigation project should at least equal its cost (Ali, 2010). Some of the factors that affect the benefits from irrigated agriculture include high input costs, low crop prices and reduced crop yields (Ali, 2010). Irrigation systems are chosen to maintain, increase crop yield or reduce uncertainty of yield or both (Matekole, 2003). Musch and Schmidt-Kallert (2000) and Schuck et al. (2005) found that changes in irrigation technology could allow farmers to continue producing even with limited amount of water and still be able to maintain high crop yields.

Previous studies reveal that using economic viability as the basis for choosing an irrigation method may not result in selection of the best alternative (Karami, 2006). Considering as many of the relevant criteria as possible in the selection process is therefore better than relying on a single criterion.

Choosing the right system can enable one to offset the cost of installation and operation of the system by first determining whether increased yield and better crop quality will result in sufficient income increase (Evans and Sadler, 2008). A suitable and effective irrigation system is also able to allow for adequate water management due to efficient water use particularly where water is scarce (Adeoti, 2009; Sharma et al., 2015). This study sought to characterize the irrigation methods practiced in Mwala, Machakos County and to establish the factors influencing the farmers’ choices of the irrigation systems.
3.2 Materials and Methods

3.2.1 Description of study area

The study was conducted in Mwala Sub County, Machakos County (Figure 3.1). The study area is located at 1°21' S and 37°26' E at an altitude of 1000-1600 meters above sea level (Figure 3.1) (Government of Machakos, 2016). The site falls in agro-ecological zone V which is described as semi-arid (Bukania et al, 2014). The average temperature ranges from a minimum of 11.1°C to a maximum of 24.3°C while total annual rainfall ranges from 500 mm to 900 mm per annum (Ellenkamp, 2004). The potential annual evapotranspiration of the area is 1435 mm (Ngile, 2015). Dominant soil groups are ultisols and oxisols (Barber et al., 1981; Karuma et al., 2015).

The high altitude areas in Machakos County receive slightly higher rainfall than the lowland areas like Mwala Sub County. The coldest month is usually July while October and March are the hottest months (ADS Eastern, 2017). River Athi together with some other dams are used as water sources for irrigation. Springs found in the hilly area of the County, supplement the other existing feeder sources (Shawiza, 2016).

The local natural resources in Machakos County include building sand, water from rivers, hills, pasture, wildlife and land (Thiong’o et al., 2016). The main economic activities and industries include farming, beekeeping, trade, dairy farming, eco-tourism and businesses (Kamau and Brownhill, 2013). Primary agricultural products consist of mangoes, paw paws, watermelons, maize, cowpeas, beans, pigeon peas, lentils, and livestock (ADS Eastern, 2017).
Figure 3.1: A Map of Machakos County showing the study location, Mwala Sub County

3.2.2 Study design and data collection

Two types of questionnaires were administered to purposefully selected farmers to characterize their perceptions on difficulty of use, installation expenses, maintenance expenses, labor requirements, energy use, and application efficiency of various irrigation systems. The survey was constructed using Likert scale, open-ended, relative rankings, dichotomous and contingency questions. Likert scale questions asked respondents to express their perceptions about a statement using a discrete scale with the categories denoting least important to most important factors. Open-ended questions in the survey left blank spaces for respondents to provide their answers.
Relative ranking questions used in the survey employed an ordered scale in obtaining farmers' opinions. Dichotomous questions provided respondents with two possible sets of responses (yes or no). Finally, contingency questions were asked to determine the respondents’ opinion on the management of their farming and irrigation systems.

The statistical population consisted of purposefully selected eighty-two farmers in Mwala, Machakos County who were registered under the Equity Group Foundation extension scheme. Forty-one of these farmers were those practicing irrigation and forty-one were farmers practicing only rainfed agriculture to compare the factors influencing their choices of irrigation systems and adoption of irrigation technology. The selection criterion was also used to compare the benefits of extension services provided by Equity Group Foundation to the farmers practicing or not practicing irrigation.

3.2.2.1 Conceptual Framework

Farmers considered social, individual, economic and physical factors when selecting an irrigation system to apply water in their farms (Fig 3.2) (Adeoti, 2009; Karami, 2006; McIndoe, 2001; Saeed, 2014). This study hypothesized that these factors affect their choices of irrigation systems.

*Individual factors*

The age, sex, education level and agricultural work experience of the farmer are factors expected to affect the choice of irrigation system. The quality of labour is influenced by the capacity to work and select a given irrigation system which is majorly affected by the age, sex and level of education of the farmer.
Social factors

These involve factors such as membership of farmer to social groups, the activities that the social groups support and the training that these farmers have received on irrigation. It is expected that farmers who have been well trained on various irrigation systems especially in their social groups will be more efficient in their selection of irrigation systems.

Economic factors

These include the expenses incurred to adopt the various irrigation systems such as, installation and maintenance expenses, labor and energy costs, annual household income and the yield obtained from the various irrigation systems. Irrigation systems vary in the cost required to install and maintain them and also in the yield and income obtained which consequentially influences the return on investment.

Physical factors

The usability of various irrigation systems differs in terms of their application efficiency and even the difficulty of use. Farmers will consider different factors when deciding the irrigation timing and application rates. These factors also include the total farm size and the area of land under irrigation. This will affect the choice of irrigation systems as farmers will adopt irrigation systems that have the capacity to distribute water efficiently to the whole farm depending on the size of the farm. The source of water affects the quality and availability of water. The land ownership too influences the rights to which a farmer is able to exercise as he or she farms and the extent to which a farmer can utilize and invest in the farm.
3.2.3 Data analysis

The responses of the questionnaires were coded and entered into the Statistical Package for Social Sciences (SPSS Ver. 21) software where summary statistics (frequencies, percentages and mean contrasts) were performed. Regression analysis was also carried out to compare means and test for significance differences to establish the effect of interactions amongst the socio-economic characteristics.
3.3 Results and Discussion

3.3.1 Irrigation systems used by farmers

The respondents were asked to state the irrigation systems they had experience with and the ones they were currently using. Table 3.1 indicates that among all the irrigation methods, the highest numbers of farmers amongst those currently practicing both irrigated and rainfed farming had experience with furrow and hosepipe irrigation methods with furrow having 22 farmers (27%) and use of hosepipe having 29 farmers (35%). The farmers practicing irrigation had four main water sources including Athi River, Yatta Canal, boreholes, and Kayatta Canal. All the interviewed farmers had no experience with border and subsurface drip irrigation systems. When asked to give remarks on this, the farmers using furrow and hosepipe methods explained that the two were popular because they are less costly to install and maintain, and they did not require a pump to apply water, especially for furrow that relies on gravity. An analysis of projects done under the Farm Water Program (2015) also revealed that gravity systems such as furrow required less capital of approximately $700 for installation and maintenance as compared to pumped systems like drip and sprinkler systems that ranged from $900 to $1300, further confirming the opinions of the farmers. The farmers also acknowledged the prolonged use of the two systems in the area thus enabling them to learn and adopt from others.

Drip irrigation, sprinkler, furrow, and use of hosepipe for irrigation are the systems the farmers practicing irrigation had adopted. For the 2015 - 2016 growing season, 44% of the farmers used furrow irrigation on their crops, 10% used hosepipe, 17% used drip, 29% used sprinkler but none used basin and subsurface drip irrigation. Additionally, 6% of the farmers used more than one irrigation system in their farms depending on the crop they were irrigating.
For instance, for farmers using sprinkler systems on their farms, they interchanged with drip or furrow irrigation for french beans for they indicated that their foliage needed to be kept dry to avoid spread of pests and diseases (Masiga et al., 2014). They also mainly used furrow irrigation for crops like maize and beans, and hosepipe for majorly vegetables as one directly determines the amount of water to apply.

The respondents were then asked to identify the irrigation systems they thought were appropriate for their crops. Fifty-six percent (56%) of the respondents thought use of drip irrigation was most appropriate for their crops because it utilizes water well. However, they indicated that they do not use it because it is more costly to install and maintain.

Table 3.1: Farmers’ responses on irrigation systems they used

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Experience with system</th>
<th>System appropriate for crops grown</th>
<th>Actual system used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin</td>
<td>5.9</td>
<td>2.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Furrow</td>
<td>26.5</td>
<td>11.8</td>
<td>43.9</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>35.3</td>
<td>5.9</td>
<td>9.8</td>
</tr>
<tr>
<td>Drip</td>
<td>11.8</td>
<td>55.9</td>
<td>17.1</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>20.6</td>
<td>23.5</td>
<td>29.3</td>
</tr>
<tr>
<td>Border</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Subsurface drip</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Mean Std. dev.</td>
<td>1.323</td>
<td>0.8507</td>
<td>1.319</td>
</tr>
</tbody>
</table>

3.3.2 Factors influencing the choice of irrigation systems

A number of aspects of the factors influencing the decisions on adopting the various irrigation systems were assessed from the farmers’ responses. These included factors such as difficulty of use, energy use, labor requirements and installation and maintenance expenses.
**3.3.2.1 Difficulty of use**

The questionnaire asked farmers the degree of difficulty in using basin, furrow, hosepipe, drip, and sprinkler irrigation systems. This includes the day-to-day maintenance of equipment, relative management time and labor needed to operate, maintain and manage these systems. The farmers used a Likert scale with values from 1 to 3; with 1 being not difficult, 2-difficult and 3 very difficult to rate the degree of difficulty in using the systems. Table 3.2 indicates that respondents perceive use of hosepipe for irrigation to be the most difficult, followed respectively by basin, furrow, drip and sprinkler being the least difficult. This, they explained is because use of hosepipe is done by hand and thus more labor and management time is required to apply water to crops in a field. Furrow and basin systems were too perceived to be more difficult to use than drip and sprinkler because they require more in terms of their day-to-day maintenance of channels, relative management time and labor needed to operate. The results of the pressure systems; sprinkler and drip in this study are consistent with the findings given by Matekole (2003) from the study he undertook in Georgia where sprinkler and drip systems were found to be the least difficult to use.

**Table 3.2: Ranking of difficulty of use**

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking</th>
<th>Mean rank</th>
<th>Sample rank&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not difficult</td>
<td>Difficult</td>
<td>Very difficult</td>
</tr>
<tr>
<td>Basin</td>
<td>50.0</td>
<td>16.7</td>
<td>33.3</td>
</tr>
<tr>
<td>Furrow</td>
<td>44.4</td>
<td>48.1</td>
<td>7.4</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>12.4</td>
<td>33.3</td>
<td>54.3</td>
</tr>
<tr>
<td>Drip</td>
<td>69.6</td>
<td>17.4</td>
<td>13.0</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>72.2</td>
<td>23.8</td>
<td>4.0</td>
</tr>
</tbody>
</table>

<sup>1</sup>where 1 means the least difficult to use and 5 the most difficult
3.3.2.2 Installation and maintenance expenses

A contingency question was asked to determine if the farmers subcontracted organizations on the installation and maintenance of their irrigation systems. No interviewed farmers hired any organization to install or maintain their irrigation systems. They either did it on their own or hired a skilled casual laborer to help them. Thirty-six percent of the farmers installed and maintained their irrigation systems while sixty-four percent hired a skilled laborer to help them.

Irrigation systems vary in the costs used to install and maintain them. The respondents practicing irrigation were asked to rank the irrigation systems according to their installation and maintenance expenses with 1 being the irrigation system with the highest cost and 5 having the least cost. Table 3.3 shows that there were decreasing installation and maintenance costs from drip to sprinkler to furrow to hosepipe then basin as perceived by farmers, with drip and sprinkler systems being the most expensive. The farmers’ opinions in this study are thus consistent with the Farm Water Program (2015). In their studies, the Farm Water Program (2015) found out that pumped systems had higher capital costs of installation and maintenance than surface systems, though these costs are offset by water savings due to improved water use efficiency and labor efficiency. Another study by Amosson et al. (2011) in Texas, also found that drip and sprinkler systems have higher investment costs than surface systems like furrow and basin.
Table 3.3: Ranking on installation and maintenance expenses

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking(^2)</th>
<th>Mean rank</th>
<th>Sample rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Basin</td>
<td>0.0</td>
<td>0.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Furrow</td>
<td>0.0</td>
<td>25.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>0.0</td>
<td>0.0</td>
<td>90.9</td>
</tr>
<tr>
<td>Drip</td>
<td>84.0</td>
<td>12.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>13.6</td>
<td>59.1</td>
<td>18.2</td>
</tr>
</tbody>
</table>

**Installation expenses**

<table>
<thead>
<tr>
<th>Basis</th>
<th>Percentage ranking</th>
<th>Mean rank</th>
<th>Sample rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Furrow</td>
<td>12.0</td>
<td>12.0</td>
<td>48.0</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>0.0</td>
<td>0.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Drip</td>
<td>75.0</td>
<td>17.9</td>
<td>3.5</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>26.1</td>
<td>56.5</td>
<td>17.4</td>
</tr>
</tbody>
</table>

\(^1\)Where 1 means irrigation system has highest cost, 2 means the second highest cost and so on.\(^2\)Vertical summation of percentages do not sum to 100, because some respondents ranked more than one system and others did not rank some systems.

### 3.3.2.3 Labor and energy requirement

This includes the amount of labor required to operate a system and the quantity of fuel (energy) required to apply an acre inch of water on a farm. In the survey, labor and energy requirements were categorized into 5, where 1 represented the irrigation system with the highest labor and energy requirement and 5, the least labor and energy requirement. Table 3.4 gives the labor and energy requirements for the irrigation systems from least to highest as drip, sprinkler, basin, hosepipe then furrow. From these results, it was observed that drip and sprinkler irrigation systems were the most efficient in terms of labor and energy requirement as compared to the other three because they required the lowest amount of labor to operate and less quantity of energy.
These results are in agreement with the analysis of a series of projects under the Farm Water program (2015), which found out that drip and sprinkler systems are more labor efficient than gravity surface systems such as furrow irrigation. Moreover, Amosson et al. (2011) estimated labor and energy requirements for furrow, sprinkler and drip systems. Their study found that furrow irrigation consumed more labor and energy than sprinkler and drip.

Table 3.4: Ranking on labor and energy requirement

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking $^2$</th>
<th>Mean rank</th>
<th>Sample rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Basin</td>
<td>0.0</td>
<td>33.3</td>
<td>66.7</td>
</tr>
<tr>
<td>Furrow</td>
<td>37.5</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>21.7</td>
<td>30.4</td>
<td>26.1</td>
</tr>
<tr>
<td>Drip</td>
<td>13.6</td>
<td>18.2</td>
<td>18.2</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>23.8</td>
<td>14.3</td>
<td>14.8</td>
</tr>
</tbody>
</table>

$^1$where 1 means irrigation system has highest labor and energy requirement, 2 means the second highest labor and energy requirement and so on.

$^2$Vertical summation of percentages do not sum to 100, because some respondents ranked more than one system and others did not rank some systems.

3.3.2.4 Application efficiency

One measure of an irrigation system’s performance is application efficiency. This represents the percentage of water applied that is available to the plant’s roots for uptake. This varies amongst different irrigation systems due to variations in the design, maintenance and management of the systems. Table 3.5 indicates that farmers perceived drip irrigation to be having the highest application efficiency, followed respectively by sprinkler, furrow, hosepipe and basin. Furrow, hosepipe and basin irrigation systems result into major losses of water due to surface runoff and deep percolation, thus reducing their application efficiency.
On the other hand, drip and sprinkler systems apply water in more controlled quantities resulting in greater application efficiencies as the magnitude of the losses is lower as compared to the other three (Mohammed, 2016).

Similar studies done by Rodrigues et al. (2013) and Amosson et al. (2011) revealed that drip and sprinkler systems were more efficient than furrow systems. Amosson, for instance calculated an efficiency index to obtain the quantity of irrigation water applied in inches per acre for drip, furrow and sprinkler systems and found that drip and sprinkler systems were more efficient. Researchers on the analysis of Farm Water Program projects in 2015 too found that surface systems had low water use efficiency than drip and sprinkler systems. The farmers’ responses in this study thus concur with Rodrigues et al. (2013), Amosson et al. (2011) and the Farm Water Program analysis (2015).

Table 3.5: Ranking on application efficiency

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking</th>
<th>Mean rank</th>
<th>Sample rank²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low AE¹</td>
<td>Moderate AE¹</td>
<td>High AE¹</td>
</tr>
<tr>
<td>Basin</td>
<td>84.6</td>
<td>15.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Furrow</td>
<td>81.8</td>
<td>9.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>83.3</td>
<td>11.1</td>
<td>5.6</td>
</tr>
<tr>
<td>Drip</td>
<td>5.9</td>
<td>8.8</td>
<td>85.3</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>11.8</td>
<td>76.4</td>
<td>11.8</td>
</tr>
</tbody>
</table>

¹AE- Application efficiency, ²where 1 means irrigation system has lowest application efficiency and 5 has highest application efficiency

3.3.3 Irrigation system preferences

The survey sought the irrigation systems preferred by farmers. The farmers not using their preferred irrigation systems were further asked why they would choose the particular irrigation systems.
Eighty-five percent wished they could be using drip irrigation, 9% preferred sprinkler and 6% preferred furrow irrigation. Responses to open-ended questions posed to farmers revealed that 85% of the farmers preferred drip irrigation because of uniform application of water on fields and higher water application efficiency. When asked why they were not using their preferred irrigation systems, ninety percent of the responses from the farmers suggested that the prevalent reason was due to high capital costs to install and maintain the drip and sprinkler systems.

The farmers were also asked to rate how important various factors are to their choice of irrigation systems. These factors included purchase price, amortization period, difficulty of use, installation expense, maintenance expense, labor requirement, energy use, and water delivery efficiency. Table 3.6 shows that all the factors were actually considered by farmers to be important. Nevertheless, the purchase price and water delivery efficiency were perceived to be the most important by the farmers. Panahi (2013) and Varma et al. (2006) studies agree with this finding in which they found that finance factors are considered more than application efficiency when selecting a given irrigation system.

Table 3.6: Ranking of factors in choosing an irrigation system

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking</th>
<th>Mean rank</th>
<th>Sample rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not important</td>
<td>Important</td>
<td>Very important</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchase price</td>
<td>0.0</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>Amortization period</td>
<td>2.9</td>
<td>14.7</td>
<td>82.4</td>
</tr>
<tr>
<td>Difficulty of use</td>
<td>13.3</td>
<td>93.3</td>
<td>6.7</td>
</tr>
<tr>
<td>Installation expense</td>
<td>11.8</td>
<td>8.8</td>
<td>79.4</td>
</tr>
<tr>
<td>Maintenance expense</td>
<td>2.9</td>
<td>14.7</td>
<td>82.4</td>
</tr>
<tr>
<td>Labor requirement</td>
<td>8.8</td>
<td>41.2</td>
<td>50.0</td>
</tr>
<tr>
<td>Energy use</td>
<td>11.8</td>
<td>29.4</td>
<td>58.8</td>
</tr>
<tr>
<td>Water delivery efficiency</td>
<td>0.0</td>
<td>19.3</td>
<td>80.7</td>
</tr>
</tbody>
</table>

1where 1 means the least important factor and 7 the most important factor
3.3.4 Yield-related differences

Both groups of farmers practicing irrigated and non-irrigated farming were asked the crops they grew. They were also asked whether they believed that there is a yield advantage between irrigated and non-irrigated farming. The farmers practicing irrigation specialized in and irrigated majorly non-drought tolerant crops throughout the year. They planted at least three times a year. The crops they grew under irrigation included maize (Zea mays), tomatoes (Solanum lycopersicum), french beans (Phaseolus vulgaris), vegetables (such as Brassica oleraceae, Solanum villosum), onions (Allium cepa), bananas (Musa acuminata and Musa balbisiana), sweet potatoes (Ipomoea batatas), capsicum (Capsicum annuum), cabbage (Brassica oleracea), common beans (Phaseolus vulgaris Group), mangoes (Mangifera indica) and oranges (Citrus sinensis).

On the other hand, the farmers practicing non-irrigated farming grew crops two times a year during the two rainy seasons and relied mostly on the fruit trees like mangoes and oranges. They also grew crops like maize, beans, green grams (Vigna radiata), cowpeas (Vigna unguiculata) and pigeon peas (Cajanus cajan) whose quantity of yield was dependent on the amount of rainfall received.

Ninety seven percent of the farmers who had experience with both irrigated and non-irrigated believed that irrigated farming yields were more than non-irrigated farming. Eighty-two percent of the farmers practicing irrigation believed that the irrigation systems varied for yields produced. When asked to rank the irrigation systems with respect to the quantity of yield, 59% of the farmers adjudged that drip resulted in the highest yield production and basin the least. The responses are as indicated in table 3.7.
The results are in concurrence with Matekole et al. (2003) and Jägermeyr et al. (2015) who studied the crop yield differences among various irrigation systems and found that drip irrigation was the best and surface systems like basin and furrow produced the lowest crop yield. However, some farmers argued that it depends on which crop one is growing and under which irrigation system. For instance, some argued that furrow is the most suitable for crops that require substantial amounts of water like maize and bananas for them to yield more.

3.3.5 Quality-related differences

The farmers were asked whether they believed that there is a yield quality difference in terms of appearance, textural and nutritional quality of the harvested crops between irrigated and non-irrigated farming. Ninety-six percent of the farmers who had experience with irrigated and non-irrigated farming perceived that irrigated farming yields higher quality crops than non-irrigated farming. When asked to rank the irrigation systems with respect to the quality of the yield, 73% of the farmers perceived drip to have the highest quality of yield and basin the least. The observations are shown in table 3.7.

Arah et al. (2015) and Taylor et al. (2008) studies on the effect of irrigation on the postharvest crop quality agree with the observation that irrigation affects the quality of the harvested crops. This they found is because irrigation affects environmental conditions where the crops are produced such as temperatures, relative humidity and soil water potential, which in turn affect their growth and development and eventually their quality.

Matekole et al. (2003) too studied quality differences among various irrigation systems and found that drip and sprinkler irrigation methods produced the highest quality of yield than surface systems like basin and furrow that produced the lowest.
According to Smith et al. (2013) and the National Research Council (2009), drip and sprinkler systems yield higher quality of crops because their mode of water application is more controlled and hence result into higher water use efficiency that positively affects the quality of the harvested crop.

The farmers were also asked to state the pests and diseases that affect the quality of their harvested crops. The farmers practicing irrigation encountered more pests and diseases as compared to the farmers practicing non-irrigated farming. According to Sithanantham et al. (2002), intensive and year-round farming under irrigation, particularly of vegetables induces a continuous presence and buildup of pests and diseases, which can often reach epidemic proportions.

Thus farmers who mostly are smallholders are made to increasingly rely on pesticides to safeguard their crops. The pests like thrips, aphids, white flies, cutworms and beetles and diseases such as blight, rust and sheath rot were common among the both irrigated and non-irrigated farming. The farmers practicing irrigation had to deal with presence and buildup of these pests and more diseases like damping off, foot rot, wilts, stem rot and black rot among others and the pests including nematodes all year round.

**Table 3.7: Ranking on yield and quality related differences**

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking</th>
<th>Mean rank</th>
<th>Sample rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield-related differences</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin</td>
<td>88.2 11.8 0.0 0.0 0.0</td>
<td>1.12</td>
<td>1</td>
</tr>
<tr>
<td>Furrow</td>
<td>5.9 26.5 32.4 26.5 8.8</td>
<td>3.06</td>
<td>3</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>0.0 0.0 50.0 20.6 0.0</td>
<td>2.91</td>
<td>2</td>
</tr>
<tr>
<td>Drip</td>
<td>0.0 0.0 14.7 26.5 58.8</td>
<td>4.44</td>
<td>5</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>0.0 0.0 17.6 58.8 23.5</td>
<td>4.06</td>
<td>4</td>
</tr>
</tbody>
</table>
### Quality-related differences

<table>
<thead>
<tr>
<th></th>
<th>64.7</th>
<th>14.7</th>
<th>0.0</th>
<th>0.0</th>
<th>0.0</th>
<th>1.19</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furrow</td>
<td>11.8</td>
<td>50.0</td>
<td>38.2</td>
<td>0.0</td>
<td>0.0</td>
<td>2.26</td>
<td>2</td>
</tr>
<tr>
<td>Hosepipe</td>
<td>5.9</td>
<td>35.3</td>
<td>44.1</td>
<td>14.7</td>
<td>0.0</td>
<td>2.68</td>
<td>3</td>
</tr>
<tr>
<td>Drip</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>26.5</td>
<td>73.5</td>
<td>4.74</td>
<td>5</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>0.0</td>
<td>0.0</td>
<td>32.4</td>
<td>58.8</td>
<td>8.8</td>
<td>3.76</td>
<td>4</td>
</tr>
</tbody>
</table>

1. where 1 means irrigation system has lowest yield for yield-related differences and lowest quality for quality-related differences, 2 means the second lowest yield and quality and so on. 2. Vertical summation of percentages do not sum to 100, because some respondents ranked more than one system and others did not rank some systems.

### 3.3.6 Socio-economic characteristics of farmers practicing irrigated and non-irrigated farming

Tables 3.8 and 3.9 give the summary statistics of the socio-economic characteristics of farmers practicing irrigated and non-irrigated agriculture. The study sought the following demographic factors from respondents: age, gender, education level, years of farming experience, membership to social groups and activities supported by social groups, total farm size, acres under farming in the 2016 growing season, land ownership and form of land acquisition, farm management system, number of permanent and temporary hired farm workers, percentage of annual household income and approximate annual income from farming.

The statistics indicate that there was a significant difference between irrigated and non-irrigated farming (p<0.05) on gender as irrigated farming was male dominated while non-irrigated farming was dominated by women. In sub-Saharan Africa, there are gender specific constraints, such as poor access to education, production assets and land by women and these have direct effects on technology adoption including irrigation technologies where they are usually less likely to adopt (Ndiritu et al., 2011).
Fifty-three percent of the farmers practicing irrigation were above 51 years of age while among those practicing non-irrigated farming, the highest number of the farmers (29%) was between 41-50 years. These findings suggest that younger generations adopt irrigation technology on their farms at a lesser rate than older generations. This could be due to lack of capital to invest in irrigation and the declining popularity of farming as a career choice following societal values (Chuchird et al., 2017).

Table 3.8: Socio-economic characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Irrigated</th>
<th>Non-irrigated</th>
<th>F value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (%)</td>
<td>67.6</td>
<td>44.1</td>
<td>5.0373</td>
<td>0.02917*</td>
</tr>
<tr>
<td>Female (%)</td>
<td>32.4</td>
<td>55.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>51.9</td>
<td>48.6</td>
<td>1.8909</td>
<td>0.04512*</td>
</tr>
<tr>
<td>Years of farming experience</td>
<td>19.3</td>
<td>19.5</td>
<td>0.4637</td>
<td>0.49897</td>
</tr>
<tr>
<td>Training on irrigation (%)</td>
<td>76.5</td>
<td>55.9</td>
<td>0.0963</td>
<td>0.75753</td>
</tr>
<tr>
<td>Membership to social groups (%)</td>
<td>91.2</td>
<td>97.1</td>
<td>3.9300</td>
<td>0.05283</td>
</tr>
<tr>
<td>Total farm size</td>
<td>6.6</td>
<td>5.7</td>
<td>0.1452</td>
<td>0.03474*</td>
</tr>
<tr>
<td>Acres under farming</td>
<td>3.8</td>
<td>3.7</td>
<td>0.2688</td>
<td>0.04567*</td>
</tr>
<tr>
<td>Farm mgt.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self- mgt. (%)</td>
<td>97.1</td>
<td>97.1</td>
<td>1.6141</td>
<td>0.20969</td>
</tr>
<tr>
<td>Hired mgt. (%)</td>
<td>2.9</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent hired workers no.</td>
<td>0.5</td>
<td>0.2</td>
<td>1.2467</td>
<td>0.02032*</td>
</tr>
<tr>
<td>Temporary hired workers no.</td>
<td>4.9</td>
<td>3.0</td>
<td>2.0941</td>
<td>0.01398*</td>
</tr>
</tbody>
</table>

Significance codes: 0 '****' 0.0001 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The average range of farming experience for all the respondents was between 10 to 20 years with 30% of the farmers having more than 20 years’ experience. Even so there was no significant difference of the farming experience between irrigated and non-irrigated farming.
In addition, there was no significant difference in the number of farmers that had been trained on irrigation in both irrigated and non-irrigated farming. The results show that 77% of the farmers practicing irrigation and 56% of those not practicing irrigation were trained on irrigation.

Fifty-two percent of these farmers had been trained by the Ministry of Agriculture, 33% by non-governmental organizations like Ojay Greene, OSHO, Meru Green and TechnoServe, 10% by projects carried out by international organizations like World Bank and USAID, six percent were trained in social groups and 13% said they learnt it from the extension scheme of Equity group Foundation. Eight percent of farmers who had not been trained on irrigation but practiced it indicated they had learnt to practice irrigation from the older family members; for instance parents who had been practicing irrigation for several years.

Fifty-six percent of the farmers who had been trained on irrigation did not practice it. When asked why, seventy percent of them indicated that they did not have access to water sources due to the proximity of their farms to the water sources; 30% said they lacked capital to install the irrigation systems, pay for the extra labor and energy required and keep the pests and diseases associated with irrigation away.

The farmers practicing irrigation had four main water sources including: Athi River, Yatta Canal, boreholes, and Kayatta Canal, and they lived in close proximity with these water sources. The water was supplied to the farmers by various associations, saccos and Machakos County agents, especially those obtaining water from Athi River, Kayatta Canal and Yatta Canal. The total farm acreage and the acres under farming in the 2015-2016 growing season were significantly lower (p<0.05) in the non-irrigating farmers than in the irrigating farmers. This could mean that farmers owning larger farms rather those who had the capacity to acquire larger farms were more willing to adopt irrigation.
This is consistent with studies done by Mittal and Mehar (2016) which reported that size of land holdings and adoption of irrigation technology were positively correlated. The results also reveal that farmers practicing irrigation hired significantly more permanent and temporary workers than those that did not practice irrigation (p<0.05). 97% of farmers in both irrigated and non-irrigated farming systems managed their own farms but there was no significant difference amongst them.

The study also sought to identify the membership of the respondents to social groups and the various activities that these social groups carry out. Table 3.9 shows the percentage differences and identity of the social groups. Ninety-one percent among the farmers practicing irrigation and 97% among those not practicing irrigation belonged to social groups. It is also revealed that there was a significant difference (p<0.05) between irrigating and non-irrigating farmers on the various activities that the social groups they belonged to carried out.

Most respondents indicated that the social groups carried out all the activities including farming, financial investments and savings, welfare, and community development. This finding is supported by Adeoti et al. (2003) and Muthui (2015) who found that membership to common interest groups especially with high frequency of extension visit increase the chances of adoption of irrigation by farmers. Both farming systems also had over 50% of the farmers who had attained secondary school education but there is no significant difference in the level of education between the irrigating and non-irrigating farmers.

The number of farmers using family land for farming was highest; it was 68% for the irrigating farmers and 74% for the non-irrigating farmers. Seventy-six percent and seventy-nine percent of the irrigating and non-irrigating farmers respectively did not own title deeds for the land they were cultivating and there was too no significant difference on the forms of land acquisition between the irrigating and non-irrigating farmers.
Table 3.9 indicates that the highest number of farmers obtained over 80% of their household income from farming and there is a significant difference between the irrigating and non-irrigating farmers (p<0.001). The results also show that there was a significant difference amongst the irrigating and non-irrigating farmers on their approximate annual income at (p<0.001). Forty-four percent of the farmers practicing irrigation and 56% of those not practicing irrigation, which make up the highest percentage of the farmers had an approximate annual household income of less than Ksh. 100,000. On the other hand, 15% of the farmers practicing irrigation indicated that they obtain over Ksh. 400,000 annual household income from farming whereas none of the farmers that practiced rain-fed agriculture indicated that they obtain this.

This is in agreement with the studies of Jägermeyr et al. (2015) and Matekole et al. (2003) which revealed that irrigated farming improves household income; farmers are able to diversify their agricultural activities and sources of income, as they can grow more crops both during the dry and rainy season as compared to the non-irrigating farmers who only rely on rainfall. The irrigating farmers also benefit from a higher quality of yield that further enhances their income.

The respondents were also asked how they benefited from the extension scheme provided by Equity Group Foundation (EGF). Eighty-seven percent of the farmers indicated that they benefited from the extension scheme; eight percent said they did not feel they were gaining anything while five percent gave no response. Those who indicated they gained said the benefits included extension services on farming like fertilizer and pesticide use, record keeping and agribusiness, other than the training they had obtained on irrigation for the 13% who had been trained by EGF. Amongst them, 15% also pointed out that EGF enabled them to take loans to enhance their investment in agriculture, sampled their soil for soil tests and helped them obtain pesticides and fertilizers.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>% Irrigating</th>
<th>% Non-irrigating</th>
<th>F Value</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identity of social group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>self help</td>
<td>70.6</td>
<td>44.1</td>
<td>4.0399</td>
<td>0.049095*</td>
</tr>
<tr>
<td>women group</td>
<td>8.8</td>
<td>11.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both self and women group</td>
<td>14.7</td>
<td>41.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>5.9</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social group activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farming, welfare &amp; savings</td>
<td>29.4</td>
<td>5.9</td>
<td>6.4646</td>
<td>0.013696*</td>
</tr>
<tr>
<td>Welfare, community development &amp; savings</td>
<td>29.4</td>
<td>26.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>35.3</td>
<td>64.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>5.9</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary school</td>
<td>41.1</td>
<td>41.2</td>
<td>0.0638</td>
<td>0.801550</td>
</tr>
<tr>
<td>Secondary school</td>
<td>55.8</td>
<td>52.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tertiary level</td>
<td>2.9</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land ownership</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ownership of title deed</td>
<td>76.4</td>
<td>79.3</td>
<td>0.0407</td>
<td>0.840829</td>
</tr>
<tr>
<td>Family land</td>
<td>67.6</td>
<td>73.5</td>
<td>0.2899</td>
<td>0.592350</td>
</tr>
<tr>
<td>Family and private land</td>
<td>5.9</td>
<td>8.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private land</td>
<td>14.7</td>
<td>17.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rental contracts land</td>
<td>11.8</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household income from farming</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-20%</td>
<td>11.8</td>
<td>8.8</td>
<td>8.0953</td>
<td>0.006123**</td>
</tr>
<tr>
<td>21-40%</td>
<td>14.7</td>
<td>11.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-60%</td>
<td>14.7</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>61-80%</td>
<td>14.7</td>
<td>29.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 80%</td>
<td>58.8</td>
<td>44.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approx. annual income from farming</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ksh. 0-100,000</td>
<td>44.1</td>
<td>55.9</td>
<td>7.9895</td>
<td>0.006445**</td>
</tr>
<tr>
<td>Ksh. 100,001-200,000</td>
<td>23.5</td>
<td>20.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ksh. 200,001-300,000</td>
<td>2.9</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ksh. 300,001-400,000</td>
<td>14.7</td>
<td>20.6</td>
<td></td>
<td></td>
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<tr>
<td>Over Ksh. 400,000</td>
<td>14.7</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significance codes: 0 ‘****’ 0.001 ‘***’ 0.01 ‘**’ 0.05 ‘.’ 0.1 ‘ ’ 1
3.4 Conclusions and recommendations

The paper examined the factors influencing the choice of irrigation systems by farmers in Mwala, Machakos County. The factors that were assessed included difficulty of use, maintenance expenses, installation expenses, labor and energy requirement, and application efficiency. Respondents were asked to rank the irrigation systems including drip, furrow, sprinkler, use of hosepipe and basin according to these factors. The results revealed that farmers perceived pumped systems like drip, and sprinkler to cost more in terms of maintenance and installation expenses; these were also less difficult to use and required less labor and energy when compared to the other systems such as hosepipe and furrow, and basin irrigation. Respondents’ preferences for irrigation system were based on application efficiency, labor and energy requirements, and ease of use. Important factors in purchasing irrigation systems to farmers were water delivery efficiency, labor requirements and maintenance expenses.

The socio-economic analysis revealed that irrigated farming was male dominated while non-irrigated farming was dominated by women. In most of these demographic factors, the irrigating and non-irrigating farmers did not have significant differences except for the age of the farmers whereby most of those practicing irrigation were above 51 years of age while among those practicing non-irrigated farming the highest number of the farmers was between 41-50 years. Moreover, the total farm acreage and the acres under farming in the 2015-2016 growing season were significantly lower (p<0.05) in the non-irrigating farmers than in the irrigating farmers. The results also show that more than 50% of the farmers not practicing irrigation were trained on irrigation but do not practice it because their farms are far from any water sources.
The annual household income from farming was too significantly higher (p<0.001) among the irrigating respondents than those not irrigating. This is because irrigating farmers are able to diversify their agricultural activities and sources of income, in addition to benefiting from higher quality of yield that further enhances their income.

The implication of these findings is that costs and water delivery efficiency are important to farmers in the choice and adoption of irrigation systems. This suggests that assisting non-irrigating farmers gain access to land close to sources of water or drilling tube wells to improve access to ground water will have significant impact on adoption of irrigation. It is also important to stress that due to the capital requirement for acquisition of drip and sprinkler systems, targeted credit programs by formal financial institutions in addition to Equity Group Foundation will ameliorate availability of finances to farmers. The findings also show that for proper irrigation management for optimum yield production, more on-farm training on efficient irrigation practice should be done to improve the skills of the farmers on appropriate irrigation.
CHAPTER FOUR: FACTORS INFLUENCING FARMERS’ DECISIONS ON TIMING AND APPLICATION RATES OF IRRIGATION WATER IN MWALA, MACHAKOS COUNTY

Abstract
Arid and semi-arid regions are areas that already exhibit severe water shortages due to the low and unreliable rainfall. This study sought to assess the factors that influence the decisions of farmers on when and how much water to apply to their crops. The study further attempted to characterize the soils and estimate the flow rate and the amount of water farmers actually applied to their crops using different irrigation methods. The specific irrigation scheduling technique adopted by farmers in irrigating crop(s), the factors influencing their timing and application rates, and any additional information including the plant and soil conditions and the farmers’ source of technical advice was enquired in form of an interview questionnaire. This was administered to forty-one purposefully selected farmers that are registered under the Equity Group Foundation extension scheme. Disturbed and undisturbed soil samples were also collected from the farms of randomly selected respondents practicing the four irrigation systems, namely: furrow, drip, sprinkler irrigation and use of hosepipe for irrigation and this were analysed in the laboratory for physical and chemical soil properties. In addition, field measurements were done to estimate the timing and application rates of irrigation water. Regression analyses were conducted to establish the relationship between water timing and application rates and irrigation systems used and soil properties and the four irrigation systems using SPSS 21th volume. The results obtained reveal that farmers assessed plant conditions, soil conditions, days since last irrigation and recent rainfall as the most critical factors when determining the timing of water application on farms. Plant conditions were ranked to be the most important factors with a degree of importance of 97%, followed by soil conditions and days since last irrigation at 95% recent rainfall was third at 87%.
The irrigators also identified soil conditions, plant conditions recent temperature, recent rainfall and days since last irrigation as the most important factors in deciding the quantity of water to be applied on their crops. Farmers considered soil conditions to be the most important factor exhibiting a degree of importance 80% in terms followed by plant conditions at 75% then recent temperature at 70%, recent rainfall, 63% and then days since last irrigation at 56%. Measurements on water application amounts and flow rate indicated that applied water per irrigation event exceeded the irrigation water requirement of the crops for drip, furrow, sprinkler and hosepipe irrigation methods. For instance, mangoes and oranges exhibited the largest average difference between applied water and IR per day; and this was 75 mm and 64 mm respectively, and the least in bananas, 3 mm. Furrow irrigation displayed the highest flow rate at 0.479 liters per second on each furrow, followed by use of hosepipe for irrigation that had a flow rate of 0.232 liters per second. Drip irrigation had the least flow rate at 0.003 liters per second. The soils were too found to exhibit high coarse-textured contents thus exhibiting low moisture retention capacities and high hydraulic conductivity. Consequently, farmers applied more water that could then quickly infiltrate down into the soil; with the assumption that increasing the amount of irrigation can avoid water stress on the crops. The findings from this study show that proper irrigation scheduling is necessary as it ensures appropriate amounts of water are applied to save on water and avoid losses of nutrients through leaching. Improving extension services, for instance dissemination of information and training on the physical factors influencing irrigation scheduling such as water holding capacity of the soil, crop water use rate, and plant characteristics including rooting depth and sensitivity to water stress are of critical importance as they aid farmers to decide when and how much water to apply.

**Key words:** Irrigation scheduling, Plant conditions, Soil conditions, Irrigation requirement
4.1 Introduction

Increasing water scarcity and competition for water resources necessitates the judicious use of water in the agricultural sector (Ali, 2010). This scarcity is particularly manifested in the key agricultural areas of arid and semiarid regions. Farmers, especially in these areas therefore need to ensure proper irrigation scheduling to minimize any wastage (Irmak et al., 2011; Ngigi et al., 2005). Farmers need to have information on crop water use and soil moisture content to make effective decisions on how often and how much water to apply (Soywater, 2010). Researchers have listed various factors that enable farmers to know when and how much water is to be applied and to develop an efficient irrigation schedule. These factors include: soil properties and soil-water relationships, crop factors, availability of a water supply including the actual output of the irrigation system, and climatic factors such as rainfall and temperature (Ali and Talukder, 2008; Clemmens and Molden, 2007).

Important aspects of soil influencing irrigation scheduling include the soil type and its water holding capacity (Hanks, 2012). There is need to know how much water is available and how much of it can be depleted from the soil without necessarily affecting the crop (Jones, 2007). Different crops use different amounts of water during their growth cycles. The crop factors that influence crop water needs include crop types and their sensitivity to drought stress, cultivar, stage of crop development, leaf area, leaf type and stomatal behavior and the root length and density (Ali, 2010). Atmospheric conditions such as dry, windy and hot conditions result in high crop evapotranspiration thus crops require more water. Occurrence of rainfall also influence when or not to irrigate (Ozdogan et al., 2006).
Proper irrigation scheduling is important so as to ensure efficient use of water, energy and other production inputs such as fertilisers (Ali and Talukder, 2008). Other benefits of proper irrigation scheduling include: improved crop yields, improved crop quality, water savings, energy conservation and lower production costs (Evans and Sadler, 2008). Davis and Dukes (2010), from Florida and Kashyap and Panda (2003) from India studied the factors that result in poor irrigation management amongst irrigators and found that most irrigators fail to practise proper irrigation scheduling citing reasons such as; benefits of proper irrigation scheduling are not really discernible and water is cheap; some of which are based on inadequate understanding of crop water needs as well as outside influences. This study is an attempt to assess the factors influencing the farmers’ decisions on timing and application rates of irrigation water in Mwala, Machakos County, Kenya.

4.2 Materials and methods

4.2.1 Study area

Refer to materials and methods in Chapter 3.

4.2.2 Study design and data collection

The study was realized from survey statistics and field measurements done at the study area, Mwala, Machakos County. The specific irrigation scheduling technique adopted by farmers in irrigating crop(s), the factors influencing their timing and application rates, and any additional information including the plant and soil conditions and the farmers’ source of technical advice was obtained in form of an interview questionnaire. This was administered to the forty-one purposefully selected farmers who are registered by the Equity Group Foundation extension scheme.
4.2.2.1 Soil sampling and laboratory soil analyses for soil characterization

The soil sampling was done in the study area for laboratory soil analyses. Disturbed and undisturbed soil samples were collected from the farms of respondents practicing the four irrigation systems, namely: furrow, drip, sprinkler and use of hosepipe for irrigation making up the four main treatments. The sampling was done thrice in the farms per irrigation system in three replicates of each irrigation system in the complete randomized block experimental design. Disturbed soil samples were collected using a soil auger and the undisturbed ones were collected in core rings at a depth of 0 to 30 cm. The disturbed soil samples were air-dried then passed through a 2 mm sieve in preparation for analysis on soil texture and organic carbon. Undisturbed soil samples were used for the determination of soil hydraulic conductivity, soil moisture retention and bulk density.

Soil texture was analyzed using the hydrometer method as outlined by Anderson and Ingram (1998) and the soil organic carbon by wet oxidation method (Walkley and Black, 1934). The undisturbed soil samples were analyzed for saturated hydraulic conductivity by the constant head method as described by Hooghoudt (1934), soil moisture retention (pF) by Klute (1986) and bulk density using the core ring method by Blake (1965).

4.2.2.2 Field assessments of timing and application rates

The timing and application rates of irrigation water were assessed in the field for the various irrigation systems. The data collected in the field measurements included: flow rate, the volumes of the water applied and the dimensions of the irrigation units. From the survey statistics (see also Chapter three); four irrigation systems were used by the farmers practicing irrigation.
The irrigation period was also obtained during the survey as the irrigators were asked to indicate the planting dates. These irrigation systems were: furrow irrigation, drip irrigation, sprinkler irrigation and use of hosepipes.

The flow rate \( Q \) was assessed by measuring the time \( T \) required to fill containers of a known volume \( V \) for drip, sprinkler and hosepipe irrigation systems. Three farmers were assessed per irrigation system. Flow rate was determined by dividing the known volume of the containers \( V \) by the time taken to fill the containers \( T \) as described by Trimmer (1994), this was expressed as (Equation 4.1):

\[
Q = \frac{\Delta V}{\Delta t}
\]

\text{Equation 4.1}

Where: \( Q \) = flow rate in liter per second (l/s), \( V \) = volume in liters (l), \( t \) = time in seconds (s)

Furrow irrigation timing and application rates were estimated by first measuring the furrow lengths to about 76 meters. Flow measuring stations were then located at intervals of 15 to 30 meters along each furrow. Recording of the time water started flowing into each furrow was then done. The time at which the water in each furrow reached each station was also recorded. Measurements of the inflow stream were done periodically and the rate of flow at the time recorded.

The time at which water started to flow through the orifice plate used as the outflow measuring device was recorded and the outflow measured and recorded periodically. The final inflow-outflow measurements and the maximum depth of flow were then recorded according to the methods as outlined by Vázquez et al. (2005). The flow rate was estimated using the following expression (Equation 4.2):
$Q \times t = d \times A$ \hspace{1cm} \text{Equation 4.2}

Where: $Q =$ flow rate, in liters per second (l/s); $t =$ set time or total time of irrigation (s); $d =$ depth of water applied (mm) and $A =$ area irrigated ($m^2$).

Soil samples were also collected at trenches dug along the furrows at different depths: 0-15 cm and 15-30 cm to estimate the wetting front by measuring the differences in moisture content. This treatment was replicated three times on three of the farmers practicing furrow irrigation.

Measurement of the amount of irrigation water applied ($d$) in mm is also obtained by equation 2. It is deduced by (Equation 4.3):

$$d (mm) = \frac{Q (l/s)}{A (m^2)}$$ \hspace{1cm} \text{Equation 4.3}

Where: $Q =$ flow rate, in liters per second (l/s); $d =$ depth of water applied (mm) and $A =$ area irrigated ($m^2$).

4.2.3. Data management and analysis

Data entry on soil properties, and timing and application rates was done onto an excel spreadsheet and subjected to ANOVA using Genstat 15th version.

The statistical significance was determined at $P \leq 0.05$, while means were separated using the Fischer’s least significant difference (LSD) test. Data analysis on factors influencing timing and application rates was done using the Statistical Package for Social Sciences (SPSS Ver. 21)
4.3 Results and discussion

4.3.1 Factors influencing decisions on irrigation timing

The specific irrigation scheduling technique adopted by farmers in irrigating crop(s) for the 2015-2016 growing season was enquired. In addition, plant and soil conditions relevant to farmers in making decisions on when to apply water to crop(s) and source of their technical advice was solicited. Farmers used a Likert scale with values from 1 to 3; with 1 being not important, 2- important and 3 very important, to rank the degree of importance of current temperatures, temperature forecasts, saw others irrigate, evapotranspiration, recent rainfall, rainfall forecasts, soil conditions, plant conditions, days after planting, days since last irrigation, advice of others and labor availability on when to apply water to their crop(s). Table 4.1 summarizes respondents’ ranking of factors influencing decisions on timing of water applications.

Table 4.1: Rank of factors considered in deciding when to apply water on crops

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking</th>
<th>Mean rank</th>
<th>Sample rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Saw Others Irrigate</td>
<td>95.1</td>
<td>4.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Recent Temperature</td>
<td>24.4</td>
<td>70.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Temperature forecasts</td>
<td>36.6</td>
<td>56.1</td>
<td>7.3</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>12.2</td>
<td>41.5</td>
<td>46.3</td>
</tr>
<tr>
<td>Recent rainfall</td>
<td>0.0</td>
<td>12.2</td>
<td>87.8</td>
</tr>
<tr>
<td>Rainfall forecasts</td>
<td>24.4</td>
<td>36.6</td>
<td>39.0</td>
</tr>
<tr>
<td>Soil Conditions</td>
<td>0.0</td>
<td>4.9</td>
<td>95.1</td>
</tr>
<tr>
<td>Plant Conditions</td>
<td>0.0</td>
<td>2.4</td>
<td>97.6</td>
</tr>
<tr>
<td>Days After Planting</td>
<td>4.9</td>
<td>14.6</td>
<td>80.5</td>
</tr>
<tr>
<td>Days Since Last Irrigation</td>
<td>0.0</td>
<td>4.9</td>
<td>95.1</td>
</tr>
<tr>
<td>Advice of Others</td>
<td>85.4</td>
<td>9.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Labor Availability</td>
<td>90.2</td>
<td>7.4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

\(^1\text{Where 1 means not important, 2 means important and 3 means very important to farmers}\)
Responses obtained from the farmers revealed that all farmers timed their irrigation applications, which is very important, as they are able to account for their time and ensure they do not over irrigate or under irrigate their crops. Farmers listed the soil conditions that help determine timing of water applications as: soil moisture, soil type and topography. For plant conditions, irrigators had type of crop, and its sensitivity to drought stress, stage of crop development and fruiting. Their responses also showed that they varied their irrigation and application amounts depending on the current weather conditions. Irrigators source of advice were obtained from personal experience, extension personnel and consultants. Table 4.1 shows that majority of the farmers assessed plant conditions (98%), soil conditions (95%), days since last irrigation (95%) and recent rainfall (88%) as the most critical when determining the timing of water application on farms.

From these results, it is noted that the factors farmers considered in timing irrigation were very critical as they can reveal when the crops need water in order to avoid water stress on the crops that can lead to wilting. Studies by Morgan et al. (2010) from Florida revealed that soil properties such as soil moisture, soil type and topography and plant conditions such as type of crop and its sensitivity to drought stress, stage of crop development and root density, in addition to application interval and rainfall occurrences are important factors when determining when to irrigate crops.

Lamm and Rodgers (2015) from Central Great Plains, Kansas studied the importance of timing of irrigation and noted the various factors affecting evapotranspiration including the crop type and weather conditions.
They also recommended that evapotranspiration (ET)-based irrigation scheduling is an efficient and acceptable irrigation scheduling method as irrigators can determine irrigation needs as affected by irrigation capacity, irrigation method applied, application efficiency and the initial soil water condition at seed emergence of a given crop. These studies agree with the findings from farmers in Mwala.

4.3.2 Factors influencing decisions on irrigation application amounts

Respondents were asked to answer a dichotomous question on whether they varied the amount of water they applied on their crop(s) during growing seasons. They were also asked to rate the degree of importance (using values 1 to 3; with 1 being not important, 2- important and 3- very important) of factors such as: recent temperatures, temperature forecasts, recent rainfall amounts, rainfall forecasts, soil and plant conditions, labor availability among others in determining how much water to apply on their crops.

Table 4.2: Rank of factors considered in deciding the water application amounts

<table>
<thead>
<tr>
<th>Irrigation systems</th>
<th>Percentage ranking</th>
<th>Mean rank</th>
<th>Sample rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saw Others Irrigate</td>
<td>92.7 7.3 0.0</td>
<td>1.07</td>
<td>10</td>
</tr>
<tr>
<td>Recent Temperature</td>
<td>0.0 29.3 70.7</td>
<td>2.71</td>
<td>3</td>
</tr>
<tr>
<td>Temperature forecasts</td>
<td>12.2 48.8 39.0</td>
<td>2.27</td>
<td>7</td>
</tr>
<tr>
<td>Recent rainfall</td>
<td>0.0 36.6 63.4</td>
<td>2.63</td>
<td>4</td>
</tr>
<tr>
<td>Rainfall forecasts</td>
<td>22.0 70.7 7.3</td>
<td>1.85</td>
<td>8</td>
</tr>
<tr>
<td>Soil Conditions</td>
<td>0.0 19.5 80.5</td>
<td>2.80</td>
<td>1</td>
</tr>
<tr>
<td>Plant Conditions</td>
<td>0.0 24.4 75.6</td>
<td>2.75</td>
<td>2</td>
</tr>
<tr>
<td>Days After Planting</td>
<td>12.2 34.1 53.7</td>
<td>2.41</td>
<td>6</td>
</tr>
<tr>
<td>Days Since Last Irrigation</td>
<td>7.3 36.6 56.1</td>
<td>2.49</td>
<td>5</td>
</tr>
<tr>
<td>Advice of Others</td>
<td>75.6 17.1 7.3</td>
<td>1.32</td>
<td>9</td>
</tr>
<tr>
<td>Labor Availability</td>
<td>80.5 7.3 12.2</td>
<td>1.32</td>
<td>9</td>
</tr>
</tbody>
</table>

1Where 1 means not important, 2 means important and 3 means very important to farmers
The specific soil conditions influencing farmers’ decisions on the amount of water to apply on crops were soil moisture, soil water holding capacity, soil type, mainly the field’s soil texture, and topography. Respondents too listed the plant conditions as influencing decisions on amount of water to apply on crops. These included stress, stage of crop development, current crop rooting depth and rooting density, and crop yield.

In addition, the farmers stated that they relied on personal experience, county agents, consultants and extension publications in determining water application amounts. From table 4.2, irrigators identified soil conditions, plant conditions recent temperature, recent rainfalls and days since last irrigation as the most important factors considered in deciding the amount of water to apply on crops.

A contingency question was asked whether the farmers really took note of the amount of water they were apply on their farms. Forty percent (40%) of the farmers carefully checked the quantity of the water they applied by estimating the amount of soil wetness visually and by touch, and the length of time used to empty a tank of a known volume like 10,000 litre tank for irrigating a given size of a field depending on the type of crop. The remaining 60% timed the irrigation applications but just approximated the quantity of water applied. All irrigators except one said they varied water application amounts during the cropping season depending on the weather conditions and the growth stage of the crop.

The findings show that all the farmers timed their irrigation but 60% of the respondents did not monitor the amount of water they applied to their crops. The results also reveal that majority of the farmers did not consider carefully the amount of water they applied to their farms. Water is a very critical resource especially in water scarce areas like lowland areas of Machakos County, Mwala included, as they receive very low and unreliable rainfall.
Failing to account for the amount of water applied to crops could result to farmers applying very little water or large amounts of water that do not meet or exceed the crop irrigation requirements. Most farmers failed to consider the amount of water they applied to their crops maybe because they were charged annually not considering the amount of water they applied. It could also be because the water was availed at limited intervals by the County agents and other water providers like saccos and associations, excluding the ones with own boreholes, so in turn they could maximize when it is available.

According to studies done by Davis and Dukes (2010), and Kashyap and Panda (2003), farmers would apply excess water citing reasons such as more water can result in more yield, benefits of proper irrigation scheduling are not clearly discernible, it is too much of a bother to engage in irrigation scheduling and water is cheap. Lamm and Rogers (2015) Central Great Plains, Kansas noted that most irrigators saw no need to implement irrigation scheduling, as their marginal capacity irrigation had to be run continually throughout the season to meet corn irrigation needs. Wang et al. (2001) from Norther China Plain and Lamm and Rogers (2015) from Central Great Plains, Kansas also noted that careful consideration of the amount of water applied maximizes irrigation efficiencies by application of only the needed amount of water to replenish the soil moisture to the desired level and saves on water and energy.

4.3.3 Measurement of irrigation water

The irrigators had four main sources of water and their farms were located in close proximity to the water sources. These sources include Athi River, Kayatta Canal, Yatta Canal and borehole. The water was supplied to the farmers by various associations, saccos and Machakos County agents, especially those obtaining water from Athi River, Kayatta Canal and Yatta Canal.
Table 4.3 shows the results of the field measurements of the flow rate obtained on actual amounts of water the farmers applied per irrigation system.

**Table 4.3: Flow rate per irrigation system**

<table>
<thead>
<tr>
<th>Irrigation system</th>
<th>Flow rate (l/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hosepipe</td>
<td>0.232c</td>
</tr>
<tr>
<td>Drip</td>
<td>0.003a</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>0.074b</td>
</tr>
<tr>
<td>Furrow</td>
<td>0.479d*</td>
</tr>
<tr>
<td><strong>l.s.d.</strong></td>
<td><strong>0.0247</strong></td>
</tr>
</tbody>
</table>

* l/s per furrow

The results show that there is a huge difference in flow rate between drip and other irrigation systems. Furrow irrigation and use of hosepipe exhibit the highest flow rate and thus leading to application of the highest amount of water in liters per second (l/s). The flow rate varied significantly amongst the irrigation systems.

Drip and hosepipe methods exhibit more controlled modes of application of irrigation water thus the low flow rate in litres per second. This also influences their efficiency as they are considered to be more efficient than use of hosepipe and furrow methods. A comparative study between drip and furrow systems done by Tagar et al. (2012) in Umarkot showed similar findings, that the total volume of water used under drip irrigation system was less as compared to furrow irrigation system with drip exhibiting 468 m$^3$ and furrow 1076 m$^3$.

Al-Jamal et al. (2001) compared sprinkler, drip and furrow systems and found out that due to the differences in the modes of application of the three systems their flow rate were influenced. This significantly affected the application efficiency of the systems with drip exhibiting the highest and furrow irrigation the lowest. These studies agree with the findings from Mwala.
Table 4.4: Irrigation data for the majorly grown crops in Mwala per irrigation system

<table>
<thead>
<tr>
<th>Crops</th>
<th>Drip</th>
<th>Sprinkler</th>
<th>Hosepipe</th>
<th>Furrow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Applied water (mm)</td>
<td>Frequency (days per week)</td>
<td>Applied water (mm)</td>
<td>Frequency (days per week)</td>
</tr>
<tr>
<td>Maize</td>
<td>40.9</td>
<td>1</td>
<td>48.1</td>
<td>2</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>45.6</td>
<td>2</td>
<td>56.8</td>
<td>2</td>
</tr>
<tr>
<td>French beans</td>
<td>43.6</td>
<td>2</td>
<td>52.0</td>
<td>1</td>
</tr>
<tr>
<td>Vegetables</td>
<td>26.4</td>
<td>2</td>
<td>30.2</td>
<td>2</td>
</tr>
<tr>
<td>Bananas</td>
<td>50.3</td>
<td>2</td>
<td>59.0</td>
<td>2</td>
</tr>
<tr>
<td>Mangoes</td>
<td>69.1</td>
<td>2</td>
<td>84.1</td>
<td>1</td>
</tr>
<tr>
<td>Oranges</td>
<td>64.4</td>
<td>2</td>
<td>83.5</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.4 shows the amount of water applied for the various crops. Furrow irrigation exhibited the highest quantities of irrigation water application per irrigation event as compared to the other systems. Drip had the least but required more applications especially for mangoes and oranges. This data collection on irrigation monitoring was done in the mid growth stage of the crops during the dry season.

These findings show the effect of the various methods of irrigation and how they influence the amount of irrigation water applied for different crops. From the results, it is revealed that drip irrigation exhibited the lowest amount of water applied per irrigation event and furrow exhibited the highest. This also affects their application efficiencies as drip exhibited the highest application efficiency and furrow irrigation the lowest.

Similar results were realized by Asif et al. (2016) from the study they carried out in Southern New Mexico and Tagar et al. (2012) in Umarkot where they observed that the crops investigated consumed less water under drip irrigation as compared to furrow irrigation system.
This positively affected the yield of crops and conserved water under drip irrigation thus encouraging farmers to adopt more efficient irrigation methods.

4.3.4 Soil-water relationships

The type of soil and its hydraulic properties influence its behavior upon application of water and the timing of irrigation (Thabet, 2016). Coarse textured soils including sands and loamy sands are very permeable and hold low amounts of water. On the other hand, fine textured soils like clays, sandy clays and silty clays hold large amounts of water and are slowly permeable. Good soils fall in between the two; these are the medium textured soils including loams, clay loams and silt loams (Durner and Flühler, 2005).

Table 4.5: Soil properties under different irrigation systems

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Irrigation systems</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drip</td>
<td>Furrow</td>
<td>Hosepipe</td>
<td>Sprinkler</td>
<td>L.S.D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic conductivity (cm/hr)</td>
<td>0.48a</td>
<td>0.69b</td>
<td>3.09d</td>
<td>2.36c</td>
<td>0.09</td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Soil moisture retention (vol%)</td>
<td>95.80c</td>
<td>92.67c</td>
<td>81.00a</td>
<td>87.89b</td>
<td>3.54</td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Bulk density (g/cm³)</td>
<td>1.31a</td>
<td>1.47b</td>
<td>1.65c</td>
<td>1.54b</td>
<td>0.08</td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>0.76ab</td>
<td>0.91b</td>
<td>0.68a</td>
<td>0.84b</td>
<td>0.15</td>
<td></td>
<td>0.037</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>64a</td>
<td>72bc</td>
<td>77c</td>
<td>71b</td>
<td>6.10</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>29b</td>
<td>22ab</td>
<td>20a</td>
<td>23a</td>
<td>4.77</td>
<td></td>
<td>0.011</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>7a</td>
<td>6a</td>
<td>3a</td>
<td>6a</td>
<td>3.65</td>
<td></td>
<td>0.105</td>
</tr>
</tbody>
</table>

Soil texture significantly influences other soil hydraulic properties like bulk density, hydraulic conductivity and soil moisture retention. Good amounts of soil organic carbon in the soil enhance their moisture retention capacity, bulk density and hydraulic conductivity (Rawls et al., 2004). Table 4.5 shows the results of the data for the laboratory analysis of the soil hydraulic properties.
The soils under the various irrigation systems had significantly different sand contents (p<0.01). Under the use of hosepipe, soils exhibited the highest sand content while those under drip irrigation exhibited the least. This could have resulted from the higher impact energy from the water in use of hosepipe for irrigation. This in turn led to the heavier material, mainly sand remaining on the surface as the lighter contents, silt and clay are washed away by water or wind erosion.

Similar findings were obtained by McKenzie (2010) and Mbagwu (2003) who noted that the impact energy resulting from rainfall or irrigation droplets are able to cause considerable degradation and breakdown of soil aggregates. The soils under hosepipe irrigation will thus require more water to be applied and more frequently as the higher sand contents increases the permeability of the soil making it lose water through infiltration faster and also reduces its capacity to hold water (Thabet, 2016; Banda, 2006). The soil bulk density, saturated hydraulic conductivity and moisture retention capacity also varied as the sand, clay and silt contents varied under the different irrigation systems.

The soils with higher sand contents had higher saturated hydraulic conductivities than those with higher contents of finer textured soil contents. This is because the soil texture affects its bulk density that in turn affects its flow rate, thus a lower bulk density results into a higher hydraulic conductivity (Saxton and Rawls, 2006; Bormann and Klaassen, 2008). These results also agree with the studies of Wang et al. (2015) who found that soils with high coarse- textured soil contents had higher bulk densities as compared to those with higher contents of silts and clays. They also noted that total flow rate increases with increase in the size of soil pores. In addition, soils with higher sand contents have low water retention capacities.
This could be due to the presence of higher proportion of macropores caused by the higher sand contents (Walczak et al., 2002). The results also show that the percentage of organic carbon was generally low amongst the irrigation systems that were investigated and this ranged from 0.68% in use of hosepipe to 0.91% in furrow.

Studies by Azlan et al. (2012) reveal that soils with less than 1% organic carbon concentration are majorly limited to arid and semiarid areas just like the study site mainly because of the high temperatures and low soil moisture contents characterized to the soils in these areas. The researchers explain that the high temperatures restrict water absorption and lead to a high rates of decomposition of organic matter. Thus, most of the carbon escapes into the atmosphere in form of carbon dioxide resulting in low organic carbon contents in the soil.

Apparently, the farmers involved in this study were not applying manure in their farms which could enhance the level of the organic matter in the soil. Soil organic carbon content influences primary soil hydraulic properties like bulk density, soil water retention and hydraulic conductivity (Rawls et al., 2004). When soils have significantly high contents of organic carbon, this increases the volume of water available at field capacity and improves the saturated hydraulic conductivity. Soils with significantly higher organic carbon contents also exhibit lower bulk density (Hugar and Soraganvi, 2014).

According to Wang et al. (2014), arid and semiarid environments are characterized by low organic carbon contents of less than 1%. This is because of the inherent unique features characterized to them including limited precipitation, coarse soil particles, highly intensified wind erosion and shallow rooted plants that result in small biomass productivities and hence low soil carbon inputs.
Additionally, the fragile nature of these regions predisposes them to degradation in which small changes in soil conditions are able to modify the balance of the soil carbon cycle and increase loss of the carbon from the soil into the atmosphere.

### 4.4 Conclusions and recommendations

This paper assessed the various factors that were considered by farmers when deciding on irrigation timing and application amounts. The farmers’ responses showed that plant conditions, soil conditions, days since last irrigation and recent rainfall were the most important factors in determining how they timed water application on their farms. From these, plant conditions were ranked to be the most important factor with a degree of importance of 97%, followed by soil conditions and days since last irrigation at 95% recent rainfall was third at 87%.

The farmers also identified soil conditions, plant conditions, recent temperature, recent rainfalls and days since last irrigation as the most important factors in deciding the quantity of water applied to crops. They considered soil conditions to be the most important factor when deciding the amount of water to apply, this exhibiting a degree of importance 80% in terms followed by plant conditions at 75% then recent temperature at 70%, recent rainfall, 63% and then days since last irrigation at 56%. Farmers then listed the soil conditions and plant conditions that help determine timing of water applications. The soil conditions included antecedent soil moisture, soil type and topography and for plant conditions, irrigators had crop type, stage of crop development and fruiting.

The study went further to estimate the amount of water the farmers actually applied on their farms, as well as to characterize the soil hydraulic properties that would influence the infiltration rate and available water content important for water availability to crops.
Results obtained show that there was a significant difference in flow rate (p<0.05) between drip, sprinkler, furrow and use of hosepipe irrigation methods. Furrow irrigation and use of hosepipe exhibited the highest flow rate of 0.479 l/s per furrow and 0.232 l/s in hosepipe thus leading to application of the highest amount of water in liters per second (l/s). These revealed that the differences in irrigation methods used influenced the amount of water the farmers applied to their farms as it affected the rate of flow of the water.

The results on the amount of water applied per irrigation system on the different crops revealed that in furrow irrigation, the highest quantities of water application was done per irrigation event as compared to other systems. Drip had the least but required more applications especially for mangoes and oranges. It is noted that drip irrigation exhibits higher application efficiency on all the crops as it ensures a controlled moisture supplying water drop by drop to the root zone of the plants and thus a large amount of water away from the root zone is saved.

Data from soil analyses too revealed that the soils had high coarse-textured contents especially in use of hosepipe and furrow irrigation methods, thus exhibiting low moisture retention capacities and high hydraulic conductivity. Consequently, farmers applied more water that could then quickly infiltrate down into the soil; with the assumption that increasing the amount of irrigation can avoid water stress on the crops. This shows that proper irrigation scheduling is necessary as it ensures appropriate amounts of water are applied to save on water and avoid losses of nutrients through leaching. In addition, the farmers can be advised to apply farm manure on their farms to increase its organic matter content and enhance its water holding capacity.

These findings too reveal that farmers have limited knowledge on proper and appropriate irrigation scheduling which mostly results to applying of excess water especially in surface irrigation methods, thus wasting water.
Excessive application of water can result in waterlogged conditions that suffocate roots that can negatively influence the crop yield; this can be avoided by applying correct amounts of water and at the right time. Since all the farmers timed their irrigation, they can be encouraged to reduce the amount of time they use to water their crops for this will reduce the amount of water applied thus conserving much of the water wasted. They could also be charged per unit of water that they apply for this would then encourage them to avoid water wastage as it could cost them more.

Improving extension services through dissemination of information and training on the physical factors influencing irrigation scheduling such as water holding capacity of the soil, crop water use rate, and plant characteristics including rooting depth and sensitivity to water stress are of critical importance as this will aid farmers to decide when and how much water to apply.
CHAPTER FIVE: ESTIMATION OF CROP WATER REQUIREMENTS OF MAJOR CROPS IN MWALA, MACHAKOS COUNTY USING THE FAO-CROPWAT MODEL

Abstract
It is vital to have an understanding of crop water requirements (CWR) of various crops grown under irrigation especially in arid and semi-arid regions. This will then enable efficient use of water and better irrigation practices like scheduling as the supply of water through rainfall is limited in these areas. The crop water needs of the major crops grown in Machakos County were calculated using the FAO-CROPWAT model using meteorological parameters. This study therefore estimated the crop reference evapotranspiration (ET₀), actual evapotranspiration (ETᵣ) and the irrigation requirements of the high value crops grown in the area. These included maize (Zea mays), tomatoes (Solanum lycopersicum), french beans (Phaseolus vulgaris), vegetables (such as Brassica oleraceae, Solunum villosum), bananas (Musa acuminata and Musa balbisiana), mangoes (Mangifera indica) and oranges (Citrus sinensis). The respective climatic data from 1986 to 2016 was collected from the Katumani Meteorological Station. Crop and soil data were then collected directly from the field using and interview questionnaire and by observation. All these data was then keyed in to the FAO CROPWAT 8.0 software. The Penman-Monteith method was utilized in the estimation of the ET₀. The crop coefficients (Kᵣ) of various growth stages of the crops were used in the adjustment and estimation of actual evapotranspiration (ETᵣ) by computing the water equilibrium of the irrigation water requirements. The results indicated that the mean annual reference evapotranspiration was at 1914 mm. Most of the months except April, May, November and December had relatively high values, greater than 150 mm per month. Average monthly values were lowest in May where the ET₀ was 139 mm at the climax of the rainy season, and 181 mm on the highest in February within the dry season.
The ET$_c$ and the crops’ irrigation requirements for the crops were estimated; maize had the lowest ET$_c$ at 180 mm while bananas had the highest at 277 mm during the rainy season. In addition, maize had the lowest ET$_c$ at 201 mm and bananas had the highest ET$_c$ at 314 mm within the dry season. The highest total irrigation water requirement was recorded in bananas at 1216 mm during the rainy season and 1740 mm during the dry season while the lowest was recorded in french beans at 178 mm during the rainy season and 529 mm during the dry season.

It was further revealed that the applied water exceeded the irrigation requirements when these were compared to the actual amount of water applied to the crops. Mangoes and oranges exhibited the largest average difference between applied water and IR per day; and this was 75 mm and 64 mm respectively. French beans followed by 36 mm, maize, 25 mm, tomatoes, 18 mm, vegetables, 8 mm and the least in bananas, with an average difference of 3 mm. The results obtained on ET$_c$ and NIR provide a practical assessment on irrigation scheduling for crops grown in semi-arid environments of the tropics. These results can thus be used to enhance water use efficiency by better managing irrigation water withdrawal and application amounts to optimize crop production from irrigated agriculture in Mwala, Machakos County.

**Keywords:** Crop evapotranspiration, Reference evapotranspiration, Phenological stages, Irrigation water requirement, CROPWAT model
5.1 Introduction

Water scarcity is one of the major challenges affecting more than 1.1 billion people globally (Network, 2010). Agriculture consumes the largest amounts of water in the globe today and most of this water loss is as a result of evapotranspiration (Barrow, 2016). The chronic food insecurity in sub-Saharan Africa is mainly because 85-95 per cent of agriculture is dependent on rainfall that is highly inadequate (Boon, 2015). Improved agricultural water productivity is thus required to help meet the rising demands for agricultural production to enhance food security (Molden et al., 2010).

Irrigation technology has the potential to enhance availability of water when conducting agricultural activities in water scarce areas especially those affected by aridity in Africa (Kohpahie et al., 2003). Agriculture can be enhanced by use of appropriate irrigation technologies and adequate water management (Adeoti, 2009). Farmers can ensure adequate water management by either maintaining or reducing water use on their farms without any negative impact on crop yields and profit (Enciso et al., 2015). Improving water use efficiency in irrigated farming can also help realize the full benefits of other production inputs, like fertilizers, high-quality seeds, tillage, labor, energy and machinery (Sharma et al., 2015).

Productivity of most crops in Machakos County has most often been recorded to be lower than the averages of other counties countrywide. Crop production in the County that is purely rainfed yields below 1 ton per hectare while the national average is above 3 tons per hectare (D’Alessandro et al., 2015; Kavoi et al., 2014; Kibaara et al., 2009).

Low and unreliable rainfall experienced in the area and the low moisture retention capacity of soils result into continued soil moisture deficit (Butterfield et al., 2016). These are considered as some of the main factors limiting high agricultural productivity in the County.
Previous studies done by Surendran et al. (2015) and Ngigi (2002) reveal that irrigation enhanced yield levels when compared to non-irrigated farming. Most farmers lack sufficient precise information on timing of irrigation and application rates for crops, and this mainly leads to inadequate and inefficient irrigation.

Precise information on crop water needs, the type of soil and climatic conditions is required to improve irrigation water productivity and achieve efficient water resource planning and management. Rainfall and evapotranspiration are very important weather parameters in the determination of water balance in crops as they affect their crop and irrigation water needs (Pereira et al., 2015). Studies on these weather parameters are thus crucial in defining the levels of risk on investments in irrigated agriculture.

The crop water requirement gives the quantity of water that is essential for compensation of the fraction of water lost through evapotranspiration from a crop field (Ouda et al., 2016). Besides, irrigation requirement gives the quantity of water that must be supplied to crops throughout the growing season (Welbaum, 2015). Various models are used to estimate the crop water needs for a number of crops grown under irrigation. Some of these models include the FAO CROPWAT model, the crop water requirement satisfaction index (WRSI) (McNally et al., 2015) and the BSim model (Seidel et al., 2016).

The CROPWAT computer program is used to calculate the crop water requirements and the amount of water that is vital for an irrigation to take place, taking into account the characteristics of the soil, data collected on the prevailing climate and that of crops grown in the study area (FAO Water, 2015). The program can also enable one to develop irrigation schedules in addition to evaluating irrigation practices of farmers and estimating performance of crops under irrigated and non-irrigated conditions (Surendran et al., 2015).
The FAO Penman-Monteith method (Pereira et al., 2015) was preferred for use in this study in
determination of the reference evapotranspiration ($ET_0$) as it is reported to provide very
consistent values on actual crop water use data worldwide (Allen et al., 2005; Cai et al., 2007;
Lo´pez-Urrera et al., 2012).

Scientific crop water requirements are essential in ensuring efficient scheduling of irrigation and
water management, design of canal capacities, planning of water resources, regional drainage
and research in reservoir operation. Sufficient information on crop water and irrigation
requirements specific to Machakos County is lacking among the farmers practicing irrigation for
most of the high value crops grown in the County. This paper is thus an attempt to calculate the
crop water needs of the main high value crops grown in the County using FAO CROPWAT
model.

5.2 Materials and methods

5.2.1 Study site

Refer to materials and methods, chapter 3.

5.2.2 Study design and data collection

5.2.2.1 Crop water requirement

The method used to determine the crop water requirement was done using the FAO CROPWAT
model applying the procedures described by FAO Water (2015). Data requirements for the
model included: crop, soil and climate data.
Meteorological data

To calculate this, the respective climatic data was collected from the Katumani meteorological station. The data used for ET₀ computation was the meteorological data obtained from the station; for instance minimum and maximum temperatures (°C), wind speed in km per day, rainfall data in mm, relative humidity (maximum and minimum, in %) and the hours of sunshine, and the physical data such as altitude, latitude and longitude.

The climatic records obtained were then adjusted into the format accepted by CROPWAT 8.0. The rainfall data collection was also obtained from the meteorological station. Rainfall records from a range of years (15–30) were collected to allow for a calculation of rainfall probabilities.

Crop data

The data on the crops grown and their cropping pattern was collected by a local survey on the farms. Some of the crops observed in the field that were mainly grown under irrigation were maize (Zea mays), tomatoes (Solanum lycopersicum), french beans (Phaseolus vulgaris), vegetables (such as Brassica oleraceae, Solanum villosum), bananas (Musa acuminata and Musa balbisiana), mangoes (Mangifera indica) and oranges (Citrus sinensis). The other crops majorly grown under rainfed conditions were pigeon peas and cowpeas. Field observations, interviews with field officers and farmers were also used to aid in the assessment of the existing cropping pattern.

The needed field information that was obtained included data on crops grown and their varieties, planting and harvesting dates, indicative levels of yield and irrigation practices including the field methods of irrigation, depths of irrigation application and frequencies and intervals of irrigation. Details such as planting season, crop duration, depth of active root zone were also obtained by field observation and secondary sources.
Crop coefficient values ($K_c$) used in this study are given in Table 5.2. Specific $K_c$ values were used for specific stages of annual and seasonal crops such as planting, mid- and late growth stages. For perennial crops like mangoes oranges and bananas, $K_c$ value of late growth stage-maturity, was used for the whole year.

**Crop evapotranspiration**

The FAO Penman-Monteith Method (Allen et al., 2005) was used to determine the Reference Evapotranspiration ($ET_0$) using the Equation 5.1.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T} + 273\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where $ET_0 =$ the reference crop evapotranspiration (mm day$^{-1}$); $R_n =$ net radiation on the crop surface in MJ m$^{-2}$ per day; $G =$ soil heat flux density (MJ m$^{-2}$ day$^{-1}$); $T =$ average air temperature per day at a height of 2 m ($^0C$); $u_2 =$ speed of wind at a height of 2 m in m s$^{-1}$; $e_s =$ vapour pressure at saturation (kPa); $e_a =$ actual vapour pressure; $e_s - e_a =$saturation vapour pressure deficit (kPa); $\Delta =$ slope vapour pressure curve (kPa $^0C$) and $\gamma =$ psychrometric constant (kPa ($^0C$)) (Surendran, 2017).

The reference evapotranspiration ($ET_0$) is multiplied by the crop coefficient ($K_c$) to obtain crop evapotranspiration ($ET_c$), as shown in Equation 5.2.

$$ET_c = K_c \times ET_0$$
Soil data
The data utilized on the soil characteristics was acquired through laboratory soil analyses done on the soil samples collected. Available soil water content (mm/m) and depth of soil (cm) were the soil characteristics utilized to estimate crop water requirement and these were obtained from the laboratory analysis. After the collection of all these data, it was entered into the CROPWAT 8.0 program, and saved.

Crop and irrigation water needs were then calculated using the model for the majorly observed high value crops including maize (*Zea mays*), tomatoes (*Solanum lycopersicum*), french beans (*Phaseolus vulgaris*), vegetables (such as *Brassica oleraceae, Solunum villosum*), bananas (*Musa acuminata and Musa balbisiana*), mangoes (*Mangifera indica*) and oranges (*Citrus sinensis*).

5.3 Results and discussion

5.3.1 Reference Evapotranspiration (ET₀)
The mean annual reference evapotranspiration (ET₀) was estimated to be 1914 mm. Table 5.1 shows ET₀ by month. Most of the months except April, May, November and December had relatively high values, greater than 150 mm per month. The lowest monthly value of ET₀ of 139 mm was observed in the month of May when rainfall was highest during the wet season while 181 mm was the maximum and was observed in February within the dry season.

The observed differences in this show the variation of weather parameters in the area of study further emphasizing the need for precise scientific information on the crop water requirements (Wriedt et al., 2009).
Adeniran et al. (2010) also studied this and found that during the period when the wet season was at its peak the ET$_0$ was least and highest at when the dry season was at its peak. The low relative humidity and escalating temperatures resulted in increased evapotranspiration during the drier season of the year.

Low values of ET$_0$ in the rainy season especially in the short rainy season in November and December could have been as a result of high rainfall occurrences together with low temperatures and high relative humidity.

The rainy season in April and May was characterized by higher temperatures, average relative humidity and sunshine hours but low wind speed in km/day which could be the reason for the low ET$_0$. Studies of Abdalla et al. (2010) revealed that low ET$_0$ was because of the high relative humidity in China and it was affected by climatic parameters including solar radiation, relative humidity of air, temperatures and wind. Therefore, consequently ET$_0$ varied with seasons as the other climatic parameters varied.

**Table 5.1: Climate and evapotranspiration (ET$_0$) data of Mwala, Machakos County**

<table>
<thead>
<tr>
<th>Month</th>
<th>Min Temp</th>
<th>Max Temp</th>
<th>Humidity</th>
<th>Wind Speed</th>
<th>Sunshine</th>
<th>Rad</th>
<th>ET$_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>°C</td>
<td>%</td>
<td>km/day</td>
<td>Hours</td>
<td>MJ/m²/day</td>
<td>mm/month</td>
</tr>
<tr>
<td>January</td>
<td>19.0</td>
<td>30.1</td>
<td>50</td>
<td>360</td>
<td>8.8</td>
<td>22.6</td>
<td>161.52</td>
</tr>
<tr>
<td>February</td>
<td>19.8</td>
<td>31.5</td>
<td>45</td>
<td>373</td>
<td>9.5</td>
<td>24.3</td>
<td>181.68</td>
</tr>
<tr>
<td>March</td>
<td>20.6</td>
<td>31.7</td>
<td>48</td>
<td>368</td>
<td>8.8</td>
<td>23.3</td>
<td>176.16</td>
</tr>
<tr>
<td>April</td>
<td>20.6</td>
<td>31.0</td>
<td>48</td>
<td>218</td>
<td>7.9</td>
<td>21.1</td>
<td>140.88</td>
</tr>
<tr>
<td>May</td>
<td>20.5</td>
<td>31.2</td>
<td>47</td>
<td>221</td>
<td>8.7</td>
<td>21.0</td>
<td>139.68</td>
</tr>
<tr>
<td>June</td>
<td>20.1</td>
<td>30.8</td>
<td>43</td>
<td>387</td>
<td>8.2</td>
<td>19.5</td>
<td>168.24</td>
</tr>
<tr>
<td>July</td>
<td>19.7</td>
<td>29.9</td>
<td>41</td>
<td>375</td>
<td>7.7</td>
<td>19.1</td>
<td>165.12</td>
</tr>
<tr>
<td>August</td>
<td>19.0</td>
<td>30.4</td>
<td>44</td>
<td>364</td>
<td>8.6</td>
<td>21.5</td>
<td>167.28</td>
</tr>
<tr>
<td>September</td>
<td>19.5</td>
<td>31.4</td>
<td>46</td>
<td>264</td>
<td>9.7</td>
<td>24.3</td>
<td>159.60</td>
</tr>
<tr>
<td>October</td>
<td>22.1</td>
<td>33.9</td>
<td>57</td>
<td>312</td>
<td>9.7</td>
<td>24.5</td>
<td>168.48</td>
</tr>
<tr>
<td>November</td>
<td>19.4</td>
<td>28.5</td>
<td>59</td>
<td>387</td>
<td>7.0</td>
<td>19.9</td>
<td>141.36</td>
</tr>
<tr>
<td>December</td>
<td>18.8</td>
<td>29.9</td>
<td>58</td>
<td>381</td>
<td>7.3</td>
<td>20.0</td>
<td>144.72</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>19.9</strong></td>
<td><strong>30.9</strong></td>
<td><strong>49</strong></td>
<td><strong>334</strong></td>
<td><strong>8.5</strong></td>
<td><strong>21.8</strong></td>
<td><strong>1914.72</strong>*</td>
</tr>
</tbody>
</table>

*sum of mean annual reference ET$_0$ in mm per month
5.3.2 Irrigation water requirement (IR) and Crop evapotranspiration ($ET_0$)

The irrigation water requirements per crop for the different high value crops that are majorly grown under irrigation in Machakos County are given in Figure 5.1 and Figure 5.2 during the dry and rainy season respectively. The 10-day (decade) average IR was computed in estimation of the required irrigation water amounts for each crop. The highest total irrigation water requirement was recorded in bananas at 1216 mm during the rainy season and 1740 mm during the dry season while the lowest was recorded in french beans at 178 mm during the rainy season and 529 mm during the dry season. French beans had the lowest cumulative crop evapotranspiration ($\Sigma ET_c$) at 416 mm, followed by vegetables at 495 mm while bananas had the highest at 1821 mm in the wet season (Table 5.2). In addition, french beans had the lowest $\Sigma ET_c$ at 555 mm and bananas had the highest $ET_c$ at 1890 mm in the dry season. Moreover, the results showed that crop evapotranspiration ($\Sigma ET_c$) was significantly higher in crops, which had growing seasons that were prolonged when compared to those having short growing seasons. The drier period likewise exhibited a higher $\Sigma ET_c$ than during the wet season. These findings are similar to those obtained by Acharjee et al. (2017), whereby the crops that were grown over the dry season needed a higher amount of water as compared to during the wet season.

The range of irrigation water needs in short-term crops like french beans and vegetables was particularly high when there was no rain, because the reference evapotranspiration ($ET_0$) was higher with little or no rainfall. For instance, longer rainfall durations according to the number of days and reduced sunshine hours were recorded in the wet season. The $ET_c$ varied considerably as the crop developed through growth stages as it was affected by the amounts of water received through rainfall that also varied significantly with seasonal variations (Bouraima et al., 2015).
From these results, it can be inferred that planning a scientific water requirement is of great importance for the stated crops so as to achieve a higher productivity using the most optimum amount of water, once all the other agronomic practices are considered (Mehta et al., 2013).

Figure 5.1: Crop evapotranspiration (ETc), effective rainfall (Eff rain) and irrigation water requirements (Irr. Req) in mm/dec as calculated by the FAO CROPWAT model for the different high value crops grown under irrigation during the dry season

Figure 5.2: Crop evapotranspiration (ETc), effective rainfall (Eff rain) and irrigation water requirements (Irr. Req) in mm/dec as calculated by the FAO CROPWAT model for the different high value crops grown under irrigation during the rainy season
Table 5.2: CROPWAT outputs on crop coefficient (\(K_c\)), mean (mm/day), cumulative value (mm) of crop evapotranspiration (\(\Sigma ET_c\)), effective rain (mm)

<table>
<thead>
<tr>
<th>CROPWAT outputs on crop coefficient ((K_c)), mean (mm/day), cumulative value (mm) of crop evapotranspiration ((\Sigma ET_c)), effective rain (mm)</th>
<th>Rainy season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Growth</td>
<td>Length</td>
</tr>
<tr>
<td>Maize</td>
<td>Init</td>
<td>0-20</td>
</tr>
<tr>
<td></td>
<td>Deve</td>
<td>21-60</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>61-100</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>101-130</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>French</td>
<td>Init</td>
<td>0-20</td>
</tr>
<tr>
<td>Beans</td>
<td>Deve</td>
<td>21-50</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>51-80</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>81-100</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td>Init</td>
<td>0-30</td>
</tr>
<tr>
<td></td>
<td>Deve</td>
<td>31-70</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>71-110</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>111-150</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>Init</td>
<td>0-20</td>
</tr>
<tr>
<td></td>
<td>Deve</td>
<td>21-50</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>51-80</td>
</tr>
<tr>
<td></td>
<td>81-100</td>
<td>1</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>---</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>494.50</td>
<td>268.00</td>
</tr>
<tr>
<td>Bananas</td>
<td>Init</td>
<td>0-60</td>
</tr>
<tr>
<td></td>
<td>Deve</td>
<td>61-120</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>121-190</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>191-250</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1821.10</td>
<td>607.10</td>
</tr>
<tr>
<td>Mangoes</td>
<td>Init</td>
<td>0-90</td>
</tr>
<tr>
<td></td>
<td>Deve</td>
<td>91-180</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>181-270</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>271-365</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1750.60</td>
<td>812.10</td>
</tr>
<tr>
<td>Oranges</td>
<td>Init</td>
<td>0-60</td>
</tr>
<tr>
<td></td>
<td>Deve</td>
<td>61-150</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>151-270</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>271-365</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>840.80</td>
<td>548.60</td>
</tr>
</tbody>
</table>

Note: Init represents the initial phase of crops’ cycles, Deve - development phase, Mid - middle phase, Late - late phase, Σ-cumulative, Eff - effective rainfall and IR - irrigation requirement.
Table 5.2 shows the ET_c rising through the growth stages and dropping slightly at the later stages. The variations observed here can be due to the crop coefficient (K_c), expressed by the ratio of ET_c to ET_0 as shown in Equation 2. Although the K_c varied little, it was not constant in any phenological stage (Azevedo, 2007). This also expresses the seasonal crop water needs. The cumulative ET_c (ΣET_c) was too put into consideration using the development stages of the crop to ensure the analysis was accurate. During the initial stages of growth of crops, the cumulative ET_c (ΣET_c) values were relatively low compared to the other growth stages in both seasons. For instance, in maize, the values were at 13 mm for the rainy season and 16 mm for the dry season. ΣET_c values increased during day 21 to day 60 of the development cycle and are highest at the mid-season stage (61-100 d). The values fell drastically as the crop gets to the last stage of growth that is from day 101 to day 130. The ET_c values were observed to be low in the start and end when the crops were at their productive stage and greater in the mid stages during the period of observation. This was observed in all the five crops. Generally, the ET_c varied significantly throughout the development cycle of the crops majorly due to the prevailing climatic conditions and the development of the crop during the growth stages.

5.3.3 Net irrigation requirement (NIR)

The mean values for NIR of different crops are given in table 5.2. The irrigation application amounts were obtained by running the 10-day average irrigation requirements (IR). High values of total NIR of the crops were observed during the period when there was no rain than in the wet season. The irrigation requirements were higher during the months of the dry season. This could be due to severe conditions of drought and consequently the low relative humidity resulting from insufficient rainfall and high temperatures that resulted in high rates of evapotranspiration.
According to Shouqin, et al. (2014), evaporation rates were high with soil moisture decreasing drastically during the period when temperatures were at their highest, indicating a high irrigation water requirement. From figure 5.3 it is clear that the lowest rainfall was between the months of June and October, during the period when there was no rain. Table 5.2 also shows this specific period when the lowest effective rain can meet the crop water requirements.

Figure 5.3: Combined trends of ET<sub>0</sub>, temperature and rainfall in Mwala, Machakos County (1986-2016)

Surendran (2014) similarly observed that the collective effect of variations in temperature, wind, sunshine hours and declining levels of effective rainfall could have caused the irrigation requirement differences. For instance, in maize, the total effective rainfall of 50 mm was observed during the wet season as compared to 170 mm that was recorded during the dry season. This implies that more water needs to be applied on the maize in order to meet the ET<sub>c</sub> and curb the soil moisture deficit as the crop grows through this dry season. These findings show fluctuations in irrigation requirement (IR) even within a season; this further expresses the significance of the requirement of precise and more systematic planning for irrigation.
Studies by Kuo et al. (2006) in Taiwan where they estimated irrigation water requirements in a paddy field found that the rates of IR were at 962 mm during the wet season and 1114 mm in the dry season; with the annual rainfall at approximately 2500 mm. Another study carried out in Northern Benin by Bouraima et al. (2015) estimated the irrigation water requirements for rice at 384 mm in the wet season and 1149 mm when there was no rain; 581 mm effective rain was recorded in the wet season. The difference in these two studies can be due to variations in weather parameters including percentage of sunshine hours, temperature and wind. It can also be due to variation between seasons or amongst soil types (Surendran et al., 2015).

The farmers used various surface and pumped irrigation systems. The surface technologies included basin and furrow irrigation while the pumped ones included use of hosepipe, drip and sprinkler irrigation. Their sources of water included getting water directly from River Athi or through Canals like Yatta and Kayatta and this was supplied to the farmers by various associations, saccos and Machakos County agents. Others also got their water from boreholes. The amount of water they applied depended on the water sources which affected its availability and the irrigation technologies adopted. Those using canals, for instance Yatta Canal lacked water most of the time and hence tended to over-irrigate, applying more water than is required when it was available. The farmers that used hosepipe and furrow methods also tended to irrigate more water than required as these technologies will mostly have low application efficiency than the pumped systems where one is able to easily control the amount of water applied (Roth et al., 2014).

Field data was collected on the actual amount of water applied to the crops in the mid growth stage during the dry season. This was then compared to the CROPWAT computed data on irrigation water requirements to assess whether the farmers were practicing efficient irrigation application. The results from this revealed that the applied water exceeded the irrigation requirement of the crops (Figure 5.4).
The lowest average differences between applied water and the irrigation requirements were observed in vegetables, which was 8 mm and bananas, 3 mm and the largest in mangoes, 75 mm and oranges, 64 mm; followed by french beans, 36 mm, maize, 25 mm, and tomatoes, 18 mm. From these comparisons, it is revealed that farmers were irrigating more than was required on the crops especially on oranges and mangoes.

![Comparison of applied water and irrigation requirements of various crops](image)

Figure 5.4: Comparison of applied water and irrigation requirements of various crops

These results reveal that farmers over irrigated their crops probably because all farmers were charged a constant fee for the water on an annual basis and hence lacked an incentive to conserve the water to save on the cost. These results are in concurrence with Thabet (2016) in Tunisia, where he estimated flow rates and irrigation application amounts and found that the irrigators applied excess water to crops. Lamm and Rogers (2015) Central Great Plains, Kansas also noted that most irrigators saw no need to implement irrigation scheduling as their marginal capacity irrigation had to be run continually throughout the season to meet corn irrigation needs.
According to studies done by Davis and Dukes (2010), and Kashyap and Panda (2003), farmers would apply excess water citing reasons such as more water can result in more yield, benefits of proper irrigation scheduling are not clearly discernible, it is too much of a bother to engage in irrigation scheduling and water is cheap.

Excessive irrigation can have negative effects on the crop yield and quality due to increased spread of pests and diseases, lower fertility caused by leaching of nutrients and minerals and accumulation of salts on the soil surface as a result of evaporation, among other effects (Al-Ghobari, 2012). It can too result in negative cost implications especially where irrigators pay per unit of water used. The respondents obtaining water mainly from the canals and Athi River paid a fixed amount of money for the water annually and the ones who used boreholes had own boreholes. This could too be one of the reasons as to why they tended to apply excess water for they did not have an incentive to conserve it and they did not have to account for every unit financially. Sufficient knowledge on the impacts of excessive irrigation and crop water requirements of the crops they grow can thus encourage the farmers to apply just enough water on their crops.

Farmers using drip and sprinkler systems too tended to apply less excessive water as compared to furrow and hosepipe methods. For instance, in mangoes where the highest excessive amount of water was applied, 54 mm was applied in excess in drip irrigation per day, 69 mm in sprinkler, 77 mm in hosepipe, and 97 mm furrow irrigation (Figure 5.4). Adopting drip and sprinkler methods can thus help reduce water wastage as they exhibit higher application efficiencies as compared to hosepipe and furrow methods (Farm Water Program, 2015).
5.4 Conclusion and recommendations

The crop water demand of major crops grown by farmers practicing irrigation in Mwala, Machakos County, including maize, french beans, tomatoes, vegetables, bananas, mangoes and oranges was calculated by the use of the FAO CROPWAT 8.0 model. Computation of annual reference (ET₀) and crop evapotranspiration (ETₑ) was also done for the dry and the rainy seasons. From the results, effective rainfall was lower than the crop water requirements for all the crops in the dry season and for mangoes and bananas in the rainy season necessitating the need for irrigation. The results too revealed that the crops required higher amounts of water during the period when there was no rain than when there was rain. The average values of ETₑ and IR varied with respect to the soil conditions and weather changes fluctuating throughout the growth cycles of crops and between seasons. The ETₑ and the crops’ irrigation requirements for the crops were estimated; maize had the lowest ETₑ at 180 mm while bananas had the highest at 277 mm during the rainy season. In addition, maize had the lowest ETₑ at 201 mm and bananas had the highest ETₑ at 314 mm within the dry season.

Comparisons were done on irrigation water requirements and the actual amounts of water applied to the crops during the dry season of the mid stage and this indicated that the farmers over irrigated their crops. The lowest average differences between applied water and the irrigation requirements were observed in bananas, 3 mm and the largest in mangoes, 75 mm. Excessive irrigations negatively affects the crop yield and quality. This emphasizes the need for scientific planning on water resources used for irrigation. The results obtained on ETₑ and NIR provide a practical assessment on irrigation scheduling for crops grown in semi-arid environments of the tropics. These results can thus be used to enhance water use efficiency by better managing irrigation water withdrawal and application amounts to optimize crop production from irrigated agriculture in Mwala, Machakos County.
CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The farmers’ selection of irrigation system for their farms in Mwala, Machakos County considered a number of aspects including individual, social, economic and physical factors. The results revealed that farmers perceived pumped systems like drip, and sprinkler to cost more in terms of maintenance and installation expenses; they were also less difficult to use and required less labor and energy requirement when compared to the other systems like hosepipe and furrow, and basin irrigation. It is also revealed that farmers judged these two irrigation systems to perform better in terms of application efficiency followed by, furrow, use of hosepipe and basin respectively. Due to this, 85% of the farmers preferred drip irrigation, 9% preferred sprinkler and 6% preferred furrow irrigation. Important factors in purchasing irrigation systems to farmers were water delivery efficiency, labor requirements and maintenance expenses.

The farmers identified soil conditions, plant conditions, recent temperature, recent rainfalls and days since last irrigation as the most important factors in deciding the amount of water and when to apply on crops. They listed the soil conditions and plant conditions that help determine timing of water applications. The soil conditions included antecedent soil moisture, soil type and topography and for plant conditions, irrigators had type of crop, and its sensitivity to drought stress, stage of crop development and fruiting. Results from physical measurements of how much water the farmers actually apply to their crops reveal that applied water exceeded the irrigation requirement of the crops for drip, furrow, sprinkler and hosepipe irrigation methods.

The study also revealed that the major crops grown in the study area: maize, french beans, tomatoes, vegetables, bananas, mangoes and oranges consumed higher amounts of water during the period when there was no rain than when there was rain.
The average values of crop evapotranspiration (ET$_c$) and irrigation requirement (IR) varied with respect to the soil conditions and as the weather changes fluctuated throughout the growth cycles of the crops and between seasons. The ET$_c$ and the crops’ irrigation requirements for the crops were estimated; maize had the lowest ET$_c$ at 180 mm while bananas had the highest at 277 mm during the rainy season.

Maize too had the lowest ET$_c$ at 201 mm and bananas had the highest ET$_c$ at 314 mm within the dry season. The highest total irrigation water requirement was recorded in bananas at 1216 mm during the rainy season and 1740 mm during the dry season while the lowest was recorded in french beans at 178 mm during the rainy season and 529.2 during the dry season. When the irrigation requirements were compared to the actual amount of water applied to the crops it was revealed that the applied water exceeded the irrigation requirements. Mangoes and oranges exhibited the largest average difference between applied water and IR per day; and this was 75 mm and 64 mm respectively, followed by french beans, 36 mm, maize, 25 mm, tomatoes, 18 mm, vegetables, 8 mm and the least in bananas, with an average difference of 3 mm. These revealed that the farmers over irrigated their crops probably because all farmers were charged a constant fee for the water on an annual basis. These provide a practical assessment on ET$_c$ and NIR for irrigation scheduling for crops grown in semi-arid environments of the tropics.
6.2 Recommendations

Owing to the findings of this study, the following interventions are recommended:

i.) Proper irrigation scheduling is necessary as it ensures appropriate amounts of water are applied to save on water and avoid losses of nutrients through leaching. For instance, farmers in Mwala can reduce the amount of time they use to apply water to their crops for this will reduce the amount of water applied.

ii.) Scientific planning on water resources used for irrigation. Determination of crop water and irrigation water requirements can help in better managing irrigation water withdrawal and application amounts so as to optimize crop production.

iii.) More on-farm training on efficient irrigation practice to be done so as to improve the skills of the farmers on appropriate irrigation practice.

iv.) Enhancing financial support from targeted credit programs to ameliorate the capital requirement for acquisition of drip and sprinkler systems.

v.) Improving access to water through construction of tube wells and proper pumping systems especially for farmers who have been trained on irrigation but are currently not able to practice it due of lack of water.

vi.) More efficient payment schemes for the irrigation water to encourage farmers to conserve the water as they also save on the cost.

vii.) Further research is recommended on the potential benefits to the environment from increased conservation of water by proper irrigation scheduling and management.
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Matekole, A. N. (2003). Factors influencing irrigation technology and water management in Georgia (*MSc. Thesis, Graduate Faculty of the University of Georgia*).


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APPENDICES

Appendix 1: Research questionnaire on factors influencing the choice of irrigation technology among medium sized farms in Mwala, Machakos County (for farmers practicing irrigated farming)

Enumerator’s name: ________________________________________________________________

Date __/__/___ Start time ___h___ End time___h

1. General information

Name of the respondent: ____________________________________________________________

Sex of the respondent a) Male   b) Female
Age: ___
Level of education: ________________________________________________________________
Years of farming experience: ______
County________ Division: ______
Location_______Sub location: _____
Village: ______

2. Household profile

a) Do you belong to any social group?
   1) Yes 2) No

b) If yes which one?
   • Self-help group
   • Women group
   • Others(specify)

c) Which activities does the group facilitate?
   • Farming
   • Welfare
   • Community development
   • Financial investment/saving
   • Others (specify)

d) Have you had any training on irrigation?
   1) Yes 2) No
   If yes, explain (by who and where), if no, how did you come to learn about irrigation?
   __________________________________________________________

3. Land ownership/tenure and use
   a) What is your total farm size?
   b) Do you have a title deed?
      1) Yes 2) No
   c) What is your form of land acquisition?
      - Community lands
      - Rental contracts land
      - Family land (inheritance)
      - Private land (bought)
      - Others (specify)
   d) How many total acres do you currently farm? How many are under irrigation and since when___________
   e) How many years have you been irrigating? _____

4. Irrigation system
   a) Which irrigation systems do you have experience with?
      - Basin irrigation
      - Furrow irrigation
      - Border irrigation
      - Portable and semi-portable sprinkler systems
      - Drip or trickle system
      - Micro-Sprinkler
      - Subsurface drip system
      - Other System? (Specify)
   b) In order of preference, which kind of crops do you irrigate and which irrigation systems do you use? Why?

<table>
<thead>
<tr>
<th>Crop(s)</th>
<th>Irrigation system</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   c) Is the irrigation system you are using your preferred one?
      1) Yes 2) No
If no, give reasons? ________________________________________________________________

d) If you could choose any irrigation system to apply water to your irrigated crops, which one would you choose? Give reasons ________________________________________________________________

e) What is the source of water for your irrigation system? ________________________________________________________________

f) Based on your perception or experience, rate each system with respect to how difficult they are to use. 1=not difficult 2=difficult 3=difficult

<table>
<thead>
<tr>
<th>System</th>
<th>Rating</th>
<th>Reason /Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furrow irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Border irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable &amp; semi-portable sprinkler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drip or trickle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro-Sprinkler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsurface drip</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


g) Do you rotate your irrigated crops?
   1) Yes 2) No

   Explain ________________________________________________________________

h) Have you ever changed your irrigation system?
   1) Yes 2) No

If yes, why and when did you change? ________________________________________________________________

4. Irrigation management

Your preferred irrigation system

a) If you were to choose an irrigation system for your farm, how important would each of the following factors be to your choice? On a scale of 1 to 3 please rate the importance of each of the following factors. 1=not important 2=important 3= very important

<table>
<thead>
<tr>
<th>Factor</th>
<th>Rating</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amortization Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty of Use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation Expense</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. **Irrigation Timing**
   a) Do you time your irrigation application?
      1) Yes 2) No
   b) Do you monitor the amount of water applied during irrigation?
      1) Yes 2) No
   c) On a scale of 1 to 3, where 1 is not important, 2 important and 3 very important please rate the importance of each of the following factors with respect to your decision of when to apply water to your crops.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Rating</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amortization Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty of Use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation Expense</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance Expense</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor Requirement</td>
<td></td>
<td></td>
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<tr>
<td>Energy Use</td>
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<tr>
<td>Water Delivery Efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Considerations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. **Factors determining how much water to irrigate**
   a) Do you change the amount of water you apply during the cropping season?
      _____ Yes _____ No
      If yes, give a reason__________________________________________
   b) On a scale of 1 to 3, please rate the importance of each of the following factors with respect to your decision of how much water to apply to your crops. 1=not important 2=important 3= very important
<table>
<thead>
<tr>
<th>Factor</th>
<th>Rating</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saw Others Irrigate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day’s Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall Occurrence</td>
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<td></td>
</tr>
<tr>
<td>Soil Condition</td>
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<td></td>
</tr>
<tr>
<td>Plant Conditions</td>
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<td></td>
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<tr>
<td>Days After Planting</td>
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</tr>
<tr>
<td>Days Since Last Irrigation</td>
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<td></td>
</tr>
<tr>
<td>Advice of Others</td>
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<td>Labor Availability</td>
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<td>Other Management Considerations</td>
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7. **Installation expenses**
   a) Which organization did you subcontract in the installation of your irrigation system?

   b) Based on your perception or experience, please rank from 1 to 7 each of the following irrigation systems with respect to how expensive they are to install. Place a 1 next to the system that is least expensive to install, 2 beside the system that has the second lowest installation expense, and so on.

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<td>Subsurface drip</td>
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8. **Maintenance Expenses**
   a) Do you maintain your irrigation system?
      1) Yes 2) No

   Give reasons for your answer__________________________________________________________

   b) Which organization do you subcontract in the maintenance of your irrigation system?

   c) How would you rank the following irrigation systems with respect to how expensive they are to maintain. On a scale of 1 to 7, please rank each of the following irrigation systems with respect to how expensive they are to maintain. Place a 1 next to the system that is least expensive to maintain, 2 beside the system that has the second lowest maintenance expense, and so on.

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### 9. Labor and energy use

Based on your perception or experience, please rank from 1 to 7 each of the following irrigation systems with respect to how energy they require to apply an acre-inch of water and the amount of labor. Place a 1 next to the system you believe requires the least labor and energy; place a 2 beside the system you believe has the second lowest labor and energy requirement, and so on.

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### 10. Application Efficiency

How well do you believe each of the following irrigation systems performs with respect to application efficiency? On a scale of 1 to 3, with 1 being low application efficiency, 2 being moderate and 3, high application efficiency, please rate each system.
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**11. Yield and Quality of Harvested Crop**

a) Is there any yield advantage when you compare rainfed and irrigated crop farming?
   
   1) Yes 2) No

Explain____________________________________________________________________

b) How many crops do you grow in a year?

c) Based on your perceptions or experience, are there any differences in the quality of yield between irrigated and non-irrigated harvested crops?
   
   1) Yes 2) No

Explain____________________________________________________________________

d) For the crops you irrigate, do you believe some irrigation systems produce a higher quality crop than other irrigation systems?

_____ Yes _____ No

e) How would you rate three of your most important irrigation systems with respect to the quality of yield you feel they produce for your irrigated crops? Why?

1=low quality 2=medium quality 3=high quality

__________________________________________________________________________

**12. Return on Investment**

a) Do you believe different irrigation systems vary in the return on investment/ payback period?

_____ Yes_____ No
b) Please rank from 1 to 7 each of the following irrigation systems with respect to the variation in return on investment/payback period. Place a 1 next to the system you believe is fastest in return on investment, 2 beside the system that is second fastest and so on, up to 7 beside the system you believe is slowest.

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Please provide the following information to facilitate our analysis of the survey. As with all of your responses in this questionnaire, your answers are strictly confidential.

a) How do you manage your farm?
   _____ Self-management of farm _____ Hired farm manager

b) What percentage of your annual household income is from irrigated farming?
   _____ Under 10% _____ Between 10% and 25% _____ Between 26% and 50%
   _____ Between 51% and 75% _____ Greater than 75%

c) Which of the following best describes your approximate yearly farm income as contributed by irrigation?
   _____ Under KSh.50,000 _____ Between KSh.50,000 and KSh.99,999
   _____ Between KSh.100,000 and KSh.199,999 _____ Between KSh.200,000 and KSh.499,999
   _____ Greater than KSh.500,000

d) Number of permanent hired farm workers

---
e) Number of temporary hired farm workers at peak need
Appendix 2: Research questionnaire on factors influencing the choice of irrigation technology among medium sized farms in Mwala, Machakos County (for farmers practicing purely rain-fed farming)

Enumerator’s name: ___________________________________________

Date __/__/___  Start time ___h___  End time___h

1. General information

Name of the respondent: ___________________________________________

Sex of the respondent a) Male   b) Female

Age: ____

Level of education: ___________________________________________

Years of farming experience: ____

County_________ Division: _____

Location________ Sub location: _____

Village: ______

1. Household profile

e) Do you belong to any social group?

2) Yes 2) No

f) If yes which one?

- Self-help group
- Women group
- Others(specify)

g) Which activities does the group facilitate?

- Farming
- Welfare
- Community development
- Financial investment/saving
- Others (specify)

h) How beneficial are EGF services to you? __________________________

i) Have you had any training on irrigation?

1) Yes 2) No

If yes, explain (by who and where), and why then are you not practicing irrigation?

________________________________________________________________

2. Land ownership/tenure and use

f) What is your total farm size?
g) Do you have a title deed?
   2) Yes 2) No

h) What is your form of land acquisition?
   - Community lands
   - Rental contracts land
   - Family land (inheritance)
   - Private land (bought)

i) How many total acres do you currently farm?

3. Irrigation system
i) Do you have any experience in irrigation technology?
If yes, which irrigation systems do you have experience with?
   - Basin irrigation
   - Furrow irrigation
   - Border irrigation
   - Portable and semi-portable sprinkler systems
   - Drip or trickle system
   - Micro-Sprinkler
   - Subsurface drip system
   - Other system? (Specify)_______________________________

Why then are you not practicing irrigation?_______________________________

4. Crop Yield
f) How many crops do you grow in a year?

g) In order of preference, please list five types of crops that you grow.

h) Is there any yield advantage when you compare rainfed and irrigated crop farming?
   1) Yes 2) No

Explain________________________________________________________________

5. Quality of Harvested Crop

a) Based on your perceptions or experience, are there any differences in the quality of yield between irrigated and non-irrigated harvested crops?
   1) Yes 2) No

Explain________________________________________________________________

Please provide the following information to facilitate our analysis of the survey. As with all of your responses in this questionnaire, your answers are strictly confidential.

a) How do you manage your farm?
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_____ Greater than KSh.500,000

d) Number of permanent hired farm workers __________

e) Number of temporary hired farm workers at peak need __________