EFFECT OF DEFICIT IRRIGATION ON GROWTH AND YIELD OF MAIZE (*Zea mays*) IN KIBOKO RESEARCH STATION, MAKUENI COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for an award ora degree in any other institution or university.

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DEDICATION

Dedicated to my dear parents, Mr. late Robert Wani, Mrs. Esther Wani my brothers,Kenyi Samuel, Tumui and Anthony Lubajo, sisters Gune and Nancy, and my dear uncle Lokujo and Aunty Kiden for unconditionally supporting me during my field study.

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ABBREVIATIONS AND ACRONYMS.

% - Percentage

^{O}C - Degrees Centigrade

CM – Centimetres

CWU - Crop Water Use

DI - Deficit Irrigation

DAP - Di-Ammonia phosphate

ETc - Crop Evapotranspiration

ETo–Potential Evapotranspiration/Reference Evapotranspiration

FAO - Food Agriculture Organisation of the United Nations

FC - Field Capacity

HI - Harvest Index

KALRO - Kenyan Agricultural and Livestock Research Organisation

KG - Kilogram

LAI - Leaf Area Index

NI - Net Irrigation

NIR - Net Irrigation Requirement

NRMSE - Normalize Root Mean Square Error

PAR - Photosynthetic Active Radiation

RMSE - Root Mean Square Error

RCBD - Randomised Complete Block Design

SG - Ground water contributing to plant available water

USAID - United States of America International Department

USDA - United States Department of Agriculture

WP - Water Productivity

WUE - Water Use Efficiency

GENERAL ABSTRACT

The scarcity of water in semi-arid area of Kiboko, Makindu sub-county is a major contributor tolow maize yield beside climate change due to little and unreliable rainfall. Regulated deficit irrigation is a water management technique that improves water use efficiency to obtainminimal yield and irrigation cost benefit. An experiment was carried out for two seasons in Kiboko, Makindu Sub-County during 2018 and 2019 short and long rains, respectively to evaluate the response of maize growth and yield to regulated deficit irrigation in semi-arid area. The experiment was a Randomized Complete Block Design with three blocks replicated three times. The treatments were T1 (100% field capacity), T2 (75% field capacity, T3 (50% field capacity), T4 (25 % field capacity) and T5 (rain-fed) were evaluated. The highest maize yield obtained in season I was 10.9tha^{-1}recorded under full irrigation (T1) followed by 10.4tha^{-1} obtained in T2, 9.8tha^{-1} obtained in T3 (50% field capacity), 9.0tha^{-1} in T4 and the lowest maize yield was 8.4tha^{-1}recorded under rain-fed (T5) while in season II the highest maize yield of 10.2tha^{-1} was recorded in T1, followed by 9.1tha^{-1} in T2, 8.3tha^{-1} in T3, 6.0tha^{-1} in T4 and the lowest maize yield of 3.0tha^{-1} was obtained under rain-fed (T5).However,the highestwater use efficiency recorded in season I was22kgha^{-1}mm^{-1} obtained under rain-fed(T5), 19.8 kgha^{-1}mm^{-1} recorded in T3 (50% field capacity) while in season II the highest WUE of 24.8kgha^{-1}mm^{-1} was recorded in T3, followed by 23.7kgha^{-1}mm^{-1} in T2 and the lowest WUE was 16.6kgha^{-1}mm^{-1} obtained under rain-fed (T5). Two climate change scenarios (2020-2039) and (2040-2059) were projected and modelled by global circulation model (GCM) and the yield was predicted usingAquaCrop water productivity model. The GCM indicated atemperature rise of1 ^{0}C which will affect the future rainfall patterns in the study area. The model predicted rainfall to increase by 15% in season I (short rains) and reduce by 10.1% in season II (long rains) compared to the baseline climate (1986 – 2005). The predicted yield of maize will remain constant under irrigation water management thoughit will significantly vary under rain-fed conditions due to temperature rise and rainfallvariation patterns which affect the crop water requirementat 401mm. The water management practices such as 100% soil surface cover will counteract the effect of climate change by reducing soil surface evaporation, net irrigation requirement and maintaining soil moisture and temperature.

Keywords: AquaCrop, climate change, maize, deficit irrigation, net irrigation requirement

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background of study

Globally water productivity (WP) and crop yield are diminished by biophysical stresses both the biotic and abiotic stresses; of which drought, heat and cold are the abiotic stresses. Agronomists are facing the challenge of maximizing water productivity in situations of imbalances and unreliable rainfall where water becomes a limiting factor, and may affect arable land negatively. It is an important component to plants and helps in seed germination, growth and developmental, maintenance of plant life process such as photosynthesis and respiration (Umrani et al., 2016).

Water stress is a key environmental stress that has significant impacts on crop productivity worldwide and can result to a high decline in crop yield and productive capacity of the land (Ghooshchi et al., 2008). Water stress happening at maize at vegetative stage basically causes delay in silking, therefore ensuing a decrease in grain yield (Halikatti., 2012). Dry season stress at blooming and post blooming can cause up to 17-37% of yield reduction (Diallo et al., 2001; Olaoye et al., 2009). The physiological maturity stage of maize crop is slightly affected by water stress and grain filling duration is reduced as water deficit increase the gap between silking and anthesis (Pannar 2012). Reproductive and vegetative stages in maize plant which include flowering, silking, pollination and grain formation are the sensitive growth stages (Umrani *et al.*, 2016) requiring adequate amount of water. Stem and leaf growth are reduced by water stress since it limits cell expansion (Siddique et al., 2001). The consequent reduction in leaf area reduces the amount of light intercepted, hence reducing daily growth and lowering the economic yield (Jensen 1973).

Deficit irrigation (DI) is an alternative way of maximizing water use efficiency (Bouazzama *et al.*, 2012). DI can be used to supplement water to the crops, increasing water use efficiency (CWU) by allowing the plant to undergo mild water stress with minimal effect on yield and quality. Information about soil moisture techniques and crop response to moisture stress help in allocating water to deficit irrigation (Gheysari *et al.*, 2015).

Net irrigation requirement (NIR) and WUEcan be used in assessing the amount of crop productivity as a function of effective evapotranspiration and net irrigation (NI), respectively. WUE is referred to as the ratio between water used in plant cell to water lost through evapotranspiration or actual water withdrawal (m^3) (Cooper et al., 1988; Karuku et al., 2014; Koech et al., 2015; Kinama et al., 2007). Irrigation water is the amount of water supplied by the irrigation system for crop growth (m^3), also referred to as water supplied through irrigation system and includes all the water used by crops via evapotranspiration, water stored in soil column and losses through deep percolation, leaching requirement and runoff. These terms can be used together, along with their various components and variables, including additional interpreted information when evaluating DIefficiency and to understand the efficiency of water application and water stress for optimal management decisions (Gheysari et al., 2015; Nagaz et al., 2012; Geerts and Races, 2009).

Understanding of how water deficit and plant response to stresses affects yield requires knowledge on the dynamics of water deficit experienced by the crop in relation to its phenology. Crop modelling has recently been used to categorise water stress seasonal pattern as the daily consumptive use of crop (Harrison et al., 2014).

Crop water productivity (CWP) might not increase as a result of DIallocated all over the crop growing cycle. This is due to variation in the effects of water stress that occurs at different growth stages of a crop. Evaluating different growth stages of crop on yield in response to water stress is very vital (Shao et al., 2008). Therefore, cropping system and irrigation parameters of a given area requires knowledge of crop response to water stress at different growth stages (Cakir, 2004; Farré and Faci, 2006; Tilahun, 2009).

Meteorological variables such as rising temperatures, shifting precipitation regimes, and increased carbon dioxide have a biophysical impact on crop output (Parry et al 1999). The increase in the atmospheric temperature is referred to as climate change and variability. This is the variation in climatic conditions that can last for over 35 years (IPCC, 2007). Climate variability is the major cause of crop production failure in sub-Saharan Africa, particularly the poor farmers, whose livelihoods are heavily dependent on agriculture (Karuku et al, 2014). These effects can be beneficial to some agricultural systems and places while being detrimental to others (Parry et al 1996). The effects associated with this change in climatic conditions are likely to pose a great effect to the developing countries with major vulnerabilities occurring in low altitude regions (Reilly et al 2001; Darwin and Kennedy, 2000). There is therefore need to develop mechanism that will help in mitigation and adaptation during this realm of climate change and variability (Verchot et al., 2007). Because smallholder farmers operate in a dynamic context, past solutions may no longer be successful in the present. What is required is an awareness of the problem as well as alternative solutions or possibilities that can be used in a long-term way (Bouma and Jones, 2001). This condition necessitates the development of technologies to assist small-scale farmers in making decisions. These methods aid in the identification of soil fertility, water stress, and other environmental restrictions problems and possibilities. (Bontkes et al., 2003).

Maize (*Zea mays*) broadly grown throughout the world has the highest production among all the cereals. It is a vital staple nourishment in numerous countries other than being utilized as animal feed and in numerous industrial applications (Raja, et al, 2018). It is one of the most important cereals for human and animal use (Gheysari et al., 2015; Ramprasad et al., Gaddameedi, 2016). Maize production is about 1,016 million tons worldwide with more than 184 million hectares under cultivation (FAO, 2013). In 2012, maize production the worldwide was evaluated at 8.7 million tons, 27% of which came from Africa, 31% from United States, 24% from China and 8% from Brazil (Ranum et al, 2014).

Kenya depends to a greater extent on agribusiness with maize, wheat, sorghum, rice and barley as the cultivated cereals (FAO, 2011). Among the cultivated cereals in Kenya, maize is a staple food in the country (USAID, 2010) and dominates all the national food consumption, contributing highly to employment (Jayne et al., 2005; Nyoro, 2003). Maize consumption per capita is 98 kg, which ranges from 2.7 to 3.1 million metric tons of annual output (Kangethe, 2011).

Maize has high crop water and irrigation requirement and its physiology at cellular and whole plant level is affected by water stress (Ghorchiani, et al, 2018). In Sub- Saharan Africa maize production is in subsistence and small-scale farming, limited by access to quality inputs such as improved seeds, fertilizer, insecticides, irrigation water and labour. In the tropics, it is mostly grown under rain-fed agriculture, where drought alone is responsible for reduced yields by up to 80 % (Maclean, 2002). Apart from water stress, other biotic factors such as weeds, insect pest and diseases affect maize productivity (Kagoda et al., 2015).

Maize requires 500 to 800 mm of rainfall throughout the growing season with actual maize evapotranspiration (ETa) of 445 mm. Crop water use (CWU) and yield is significantly affected by water stress (Nagaz *et al*., 2012; Geerts and Races, 2009). Prediction of crop yield per applied unit of water has been recognized by several authors with an established positive relationship between water use and grain yield (Morison et al., 2008). The determination of water use efficiency (WUE) is essential in evaluating crop productivity in arid regions where water is a limiting factor (Bouazzama et al., 2012).

Crop growth models that can simulate crop response to water and their effect on yield at field level can be a vital tool in agriculture water management (Raja et al., 2018). A model combines intricate relationships between weather, soil conditions, and crop management approaches to influence crop performance and provide diagnostic solutions to problems. Crop simulation modeling has evolved over time in response to advancements in crop physiology, ecology, and computing technologies. (Mukhtar et al., 2011).

Generally, models are quite complicated as they require large number of data inputs for their simulation and calibration. Several models have been developed to aid in explaining, understanding and improving the performance of the systems. Agricultural Production Systems Simulator (APSIM), Decision Support System for Agro technology Transfer (DSSAT), CROPWAT and Aqua Crop are some of these decision support tools. Most of these tools fail to address exhaustively the complexity of small holder farmers. They require much data for them to be calibrated, are expensive, time wasting and again there is lack of knowledge on how to use them and also institutions promoting them often emphasizes on the use of one tool instead of a set (Jones et al., 2013 and Young et al., 2006).

Food and Agriculture Organization (FAO) saw it wise to develop a tool to help farmers solve the above problems, by developing a model called AquaCrop. This approach relies on small number of explicit parameters and mainly intuitive input variables that are either wisely available or easily derived. It is user-friendly, simple and requires a relatively small number of input parameters (Raes et al., 2009; Steduto et al., 2009; Karuku and Mbindah, 2020). The AquaCrop model is critical for agriculture in various parts of the world, where there are significant repercussions as a result of the increasing number of irrigated areas and, as a result, an increase in water use and climate change (Paulo et al., 2018). Much of research work on AquaCrop model under maize cultivation has been published in India (Abedinpoura et al., 2012; Fereres et al., 2007; Davies, B. Ed. 2007). AquaCrop model has been used to predict crop performance and yield (Masanganise et al., 2012; Wamari et al., 2012; Simba et al., 2013; Temba et al., 2011; Karuku and Mbindah, 2020). Changes in temperatures, rainfall and carbon dioxide concentration can be modelled to determine the effect of climate change on crop growth and yield (Rauff and Bello, 2015); (Parry et al., 2004).

1.2 Statement of the Problem

Water availability is the key factor reducing crop yield as it drives all the physico-chemical processes in plants. Water scarcity has been the factor declining crop productivity in East Africa and other regions in the world. This is attributed to the little and/or unreliable rainfall due to climatic change and farmers need information that will help them adopt to the changing rainfall pattern so as to increase production.

Kiboko area receives erratic and inadequate rainfall for crop production, when considering the average annual rainfall in Kenyaand it is located in semi-arid, agro ecological zone IV(Mwadalu, 2014). However, sustainable productivity of maize has declined due to changes in rainfall pattern and imbalanced distribution, thus limiting water availability to crops at the required growth period.Drought stress occurring at the critical growth stages of crop, often reduces optimal crop productivity and therefore leaving livelihoods at risk of poverty, malnutrition and in extreme case death due hunger and starvation. To combat such situations, DI is vital at the critical stages of plant growth to improve productivity and efficiency of plants water use.

In Kenya, smallholder farming systems considersmaize as the most important food crop with an average yield per hectareand is rated third after rice and wheat (Tilahun, 2009).

1.3 Justification

Crop water use efficiency (CWUE) is an important consideration where irrigation water resources are limiting or diminishing and where rainfall is a limiting factordue toimbalanced supply. Furthermore, the recent increase in the cost of irrigation water has leftmany producers asking question on how to manage their irrigationwater resourcesefficiently to raise productivity out of their inputs. Regardless of the situation, it is important that producers realisemaximum yield out of every depth of available water. Simply put in economic terms, the producers should minimize cost of irrigation water (production input) to maximize yield (output profit).

The reduced crop yield and productivity due to the water scarcity is as a result of prolonged drought, poor water holding capacity of the sandy textured soils of Kibokoarea and unreliable and imbalanced rainfall.It is therefore important to clearlyunderstand through investigations, how maize growth stages respond todeficit irrigationtoenhance efficient planning and scheduling of irrigation water.

Several scenarios have been modelled using climate change models that have projected an increase in global average temperature. Agriculture and the earth system in general will in future be affected by the mean increase in temperature (IPCC, 2014). Some countries especially Kenya whose economy entirely depends on agriculture, may see a major shift in its Gross Domestic Product (GDP) which is being realized even now (Nairobi Stock Exchange). The general food security status will be negatively affected by the complex effects of climate change, since the country largely depends on rain-fed agriculture. Furthermore, maize is the main caloric intake for most Kenyan population andtherefore any disruption to its production would seriously impact on food insecurity in thewhole country.

1.4 Objectives

1.4.1 Mainobjective

To evaluate the responses of maize crop to deficit irrigation in Kiboko semi-arid area.

1.4.2 Specific objectives

I. Evaluate the effect of deficit irrigation regimes on maize (Zea mays) growth, yield, and water use efficiency in the semi-arid area of Kiboko, Kenya.
II. Use of AquaCrop model to evaluate and predict climate change impact on maize (Zea mays) performances in the semi-arid area through simulation of deficit irrigation regimes in Kiboko Kenya.

1.5 Hypothesis

I. Deficit irrigation regimes have no effect on growth and yield of water use efficiency of maize.
II. Simulation of AquaCrop model under deficit irrigation on performance of maize cannot predict climate change impact in a semi-arid area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Role of Water Availability in Crop Production

The increase in crop productivity is limited by water availability. In sub-Saharan Africa, water stress is the major limiting factor in agriculturedue to inadequate and poor rainfall distribution. These variations in rainfall pattern have affected most of the small-scale farmers in sub-Saharan Africa making them obtain yield that are less than the half of the optimal yields expected (Barron and Okwach, 2005).

The interactions of physical, chemical and biochemical processes of environment influence the crop's response to water (Payero et al., 2008). Crop of the same variety have varying yield response to water deficit. In general, high-quality varieties are also the most sensitive to water stress. Low quality ones are less responsive, hence more suitable for rainfed crop production in areas that are prone to drought (Passiouru and Angus. 2010).

Quantifying the link between water use and agricultural yield is an important part of matching crops and types to optimal water and rainfall regimes. Therefore, rainfall regimes will be used as guidelines on timing and levels of irrigation for maximizing returns (Sammis et al., 2000). Crop growth and yield is reduced when water supply does not meet crop water requirement as result of water stress developed in the plant.

Low input and water stress during critical growth stages will lead to crop yield reduction. Drought occurrence, intensity, and duration.Drought timing, intensity, and duration, in combination with other location-specific climatic factors like temperature and radiation, induce variation in yield losses (Kijne et al., 2003a). Often drought result in complete crop failure or reduction in biomass yield.

Rockstrom and Fox (2003) found that continuity of irrigation is vital in sustaining production of good quality crops. Deficit irrigation can have a substantial effect to increase crop yield. The timing and depth of irrigation have an impact on crop response to irrigation, as does the water application regime.The marginal response of crops to irrigation, such as an increase in growth or yield due to more irrigation water units, offers a foundation for evaluating irrigation's economic returns.There is a point at which additional water is no longer economically viable due to decreasing returns with the degree of crop water requirement(Payero et al. 2008).

Utilizing available moisture in the soil through transpiration and little lossthrough soil evaporation, deep percolation and soil erosion is a major factor in maximizing crop yield per unit of supplied water in dry areas (Karuku et al., 2006; Rockstrom, 2000).

Drip irrigation is one of the promising technologies for rural land use system (Sijali2001; Pereira 2002; Namara et al., 2010) though expensive to install and maintain. Drip irrigation can achieve as high as 90-95% efficiency when compared with the other irrigation system and it can supply waterdirectly to the roots of the individual crops as often as desired and at a relatively low cost (Irmak et al., 2011).

2.2 Environmental factors affecting Maize Growth

Maize is adapted to wide range of climatic conditions, from tropical to sub-tropical and temperate climate (FAOAGL, 2002;Camus et al., 2006; Cairns et al., 2013). It requires annual rainfall of 250 to 5000mm and temperature of between 21 and 27^{0}C for optimal production.Maize growth under rainfed production is limited by soil moisture availability where conservation practices that retain and maintain soil moisture could be essential to increase crop growth and productivity (Rockstrom et al., 2010; Unger et al., 1991). This is because maize is prone to drought stress at any growth stage and it shows yield reduction with limited supply of water (Roygard et al., 2002;Cakir, 2004; Nelson, 2007). NeSmith and Ritchie 1992 found that tasselling and grain filling growth stages of maize lead toreduction in yield due to water stress. (Zinselmeier et al. 1995; Cakir 2004; Denmead et al., 2006)found that grain formation and growth is limited by reduction of water at this critical stage. The water stress that occurs at this stage leads to a high yield reduction at farm level, since it offers no compensation opportunities for the yield loss, such as when it occurs at the germination stage where replanting can be done.In the tropics, 17% of the annual yield of maize is lost due to water deficit and water stress (Edmeades et al., 1992; Ciais et al.,2005; Cakir 2004),however 60% of yield losses in southern Africa region is during individual season (Rosen and Scott, 1992; Denning et al., 2009).

Maize crop is sensitive to very low and very high temperatures, but it can however survive a low temperature of 5^{o}Cand high temperature of 45^{o}C.High rates of kernel abortion and yield reduction occur at temperature greater than 32^{o}C during tasselling and pollination due to speed up of the differentiation process of the reproductive parts (Nielsen, 2007). A study conducted on growth chamber by Badu-Apraku et al., 1983 found that high temperature during grain filling stage cause yield losses. A rise in daily temperature by 6^{o}C. Maize productivity depend on some important characteristics of soil as it is adopted and cultivated in different typesrangingfrom sandy to clay soil;highly acidic to highly alkaline and shallow to deep soils. Maize is sensitive to aluminium, manganese and iron toxicity at pH of less than 5, though it has some level of tolerance (Clark 1997). Active Al component tying up with P at very low pH in the soil will cause deficiency of P (Haynes et al., 2001).

Hill 2007 in his study concluded that high nitrogen, phosphorus and potassium uptake occur at the vegetative and grain filling growth stages and slow uptake during seedling establishment. Potassium uptake is largely completed at silking period whereas N and P uptake continues toward maturity. Nitrogen and phosphorus portion is taken up by leaves, shoot, stalk and tassel and are translocated into grain. The Stover contains two-third to three-fourths or more potassium. Therefore, potassium is not much depleted in the soil compared to nitrogen and phosphorus that are depleted rapidly from the soil with cash grain farming.

2.2 Water management

In semi-arid tropics, crop production is limited by water availability and effort to increase the productivity and profitability of agriculture in those areas requires efficient use of water (Barron and Okwach, 2005). Irregular occurrence of rainfall is the major key factor limiting agricultural activities, however low annual rainfall has a minimal effect on yield when compared to imbalance rainfall, and hence improving water management in agriculture is the key strategy to reduce rural poverty (Eva, 2009) as opposed to relaying on supply of large volume of water for both irrigated and rainfed farming. Rainfall variation in short-period is a major constraint to crop production. Water stress is influenced by rainfall and the amount of water vapour in the atmosphere (Guzman-Pluzola et al., 2003). The performance of crop production systems will be very difficult to relate to long term climate trends due to variation in rainfall intensity (Hay, 2007).

Inadequate and unreliable rainfall and changing patterns of rainfall is the major cause of water stress in many countries in sub-Saharan Africa (Hay, 2007). The demand on water availability, accessibility, supply and demand in Africa is at peak as it is estimated that twenty-five percentages (25%) population is currently experiences water scarcity due to climate change impact, including the predicted increase in its extremes (Wilhite, 2007). This may lead to food and water shortage for the concerned populace.

As already stated, water management for agricultural production, just like the rural agricultural productivity, is a major strategy to adopt inmitigating theadverse effects of climate changeand socioeconomic pressure on water demand in the coming decades (Wilhite, 2007). Changes in water management, availability, demand for agriculture and other competing sectors including urban development industrialization are the major factors that drive changes in water use.

2.3 Water use efficiency

The relative output obtained from the given input is refers to as efficiency (FAO, 1997); (Palacio, 1998). According (Kadigi et al., 2004), economic and financial return obtained from crop produced per volume of water used is termed as water use efficiency(Doorenbos et al., 1979). From the agronomic point of view, this is generally defined as a yield of crop obtained per volume of water (rainfall + irrigation) used to produce that yield (Fan et al., 2005).

2.4 Factors affecting water use efficiency

Crop water requirement may show some variation from farm to farm, season to season and day to day. Since WUE is a fraction of yield (Y) and water applied or need to be applied, factors affecting them (yield and water applied) will affect WUE (Ali and lafukdar, 2008). Several factors affect WUE which are grouped into natural and dynamic factor. The natural factors included climate, soils, and topography and the factor influence changes in the natural factors are grouped under dynamic or management factors.

Dynamic factors can usually be controlled though many are correlated with the natural factors. Dynamic factors include water supply, water quality, planting date, crop variety, fertility, plant spacing, irrigation scheduling, irrigation methods, cultivation and chemical spraying. These factors determine the amount of water used by the plant, growth and yields (Passioura and Angus, 2010).

2.4.1 Climate

Temperature, precipitation, solar radiation, humidity, wind movement and length of growing season are example of climatic factor. These factors control the rate of transpiration effect on the water balance of crop (Valiantzas, 2006). Evapotranspiration from the plant surface increase with an increase in intensity of solar radiation. The quantity of water available in soil and water vapour in the atmosphere is influenced by the intensity of precipitation. Transpiration rates are always low with high atmospheric humidity (Trenberth et al., 2003; Eva 2009) found that rainfall and associated humidity are correlated to water stress, crop damage and crop disease.

2.4.2 Soil factors

The storage of available water in the soil is determined by several factors such as effect aeration, texture, organic matter content, structure and soil depth (Al-Qinna and Abu-Awwad, 1998). They control soil properties and water storage in the soil. The available moisture content in the soil, directly affects the rate of water uptake by plant (Brady and Weil, 2002). The available water content needed by plant is indicated by the difference between soil moisture content at field capacity and permanent wilting point.

The rate at which the plant is required to transpire water to atmosphere is also affected by the physico-chemical properties of the soil as to maintain the rate at which it must extract water for turgidity. Absorption of water by the plant roots requires energy to water from the soil to the other parts of the plant. In low soil water content, water is held strongly on the surfaces of the soil. Thus it reduces the rate of the water uptake and transmission in the soil by the plant roots (Wan et al, 2007). Consequently, the rate of water uptake by plants gets lower and lower as the soil dries up, and easier as the soil is wetted. The range of available water also reduces in saline soil with high osmotic suction (Soria et al., 2001).

Crop rooting characteristics is influenced by texture, structure and soil depth which affects the rate of water uptake by plant roots (Zhang et al., 2009). Yield and water productivity is affected by lose of through evapotranspiration due to its effect on the plant during the major growth period. The rate of plant and leaves development is also affected by the Nitrogen levels and soil fertility (Moll et al., 1992).

2.4.3 Agronomic practices

Crop water productivity is determined by both spatial and temporal management of the crop within the farm. Crop water use can be influenced by the agronomic practices such as planting date, crop establishment, herbicides use, plant spacing, crop varietyand availability of plant nutrients in the soil, irrigation management, cultivation and role of previous crops (Khan et al, 2005; Hatfield et al.,2001).

Soil condition and properties of plant foliage will cause variation in crop water use when sprayed with chemical or purposeful use of anti-transpiration (Brady and Weil, 2002). Soil with high nutrients availability for plant growth increases plant vigour which leads to marginal increase in crop water use. Tillage operation done for extensive weed control has a minimal effect on the crop water use. Close crop spacing may produce some mulching effect resulting to some diminutive benefits to the crops. The volume of soil available for root spreading and penetration is highly affected by plant density. Plant with low population will require less water in the early stages of crop establishment than plant with high population(Rahimikhoob and Montazur, 2008).

2.4.4 Crop factor

The dynamics of soil water content is also affected directly by crop factors such as Plant type, rooting system (depth, density), rate of plant development, aerodynamic characteristics (leaf area index, stomach behaviour), crop physiological stage and tolerant to drought (Bhattarai et al., 2008). They all affect physiological ability of the plants to continue taking in water from the soil at field capacity while maintaining the vital functions even if its own potential reduces (Richards et al., 2004). When plants are young, the rate of water use is low. The consumptive use increases as the plant growth, reaches a peak during some part of the growth period, then tappers off by harvest time (Erie et al 2005). Plant height normally determines the roughness, hence the aerodynamic properties of the crop. This attribute to the proportion of water loss from the crop surface C4 plants have higher WUE than C3plants (Richards et al., 2004, Kinama, 1997)).

2.4.5 Method of irrigation

Irrigation methods are generally classified according to the manner in which water is applied to the soil. A choice should be made that avoids excess of water in one part of the field and a shortage in another. Surface, overhead, sub-surface, and drip (spot) are the major systems (Pereira el al., 2002). The emergence of other systems in irrigation comes as a result of improvement in technology and innovation in irrigation (Kijne et al., 2003; Zotarclli et al., 2005). Therefore, different irrigation cause variation in crop water use as explained below.

2.4.5.1 Surface irrigation

Surface irrigation, defined by (Hillel 1987) as the application of water stream at the field head and allowing hydrostatic pressure and gravity to spread the water over the surface throughout the field, still ranks as a vital method of irrigation, accounting for over 95% of irrigated land worldwide. Flooding, border, level basin, and furrow irrigation are the major surface irrigation systems (Pereira et al., 2002). Water is applied at interval in surface irrigation system to allow utilization of 50% of the available moisture content in root zone before the next irrigation (Hillel, 1987). However, low irrigation efficiency of surface irrigation method is the major disadvantage as it requires large amount of water, especially in arid and semi-arid areas.

2.4.5.2 Sub-surface irrigation

High undeviating water table or a relatively impervious soil stratum not too far from the soil surface is suitable for this method (Chowdary et al., 2008). This method is also known as irrigation by drainage where water table is elevated or maintained at predetermined depth (30-75cm) that allow rise of moisture by capillary action to the root zone. The method is commonly used for organic soils in order to prevent excessive oxidation or subsidence.

2.4.5.3 Sub-surface drip irrigation

Sub-surface drip irrigation is defined as the placement of permanent drip pipe tape below the surface at the depth of 20 and 40cm (Harris, 2005). Water is emitted into the soil during irrigation through the emitters along the drip. This irrigation method has several inherent advantages which includes; uniformity of water application and 50% water saving which results in high water use efficiency compared to other types of irrigation method. However sub-surface drip irrigation has a number of disadvantages, especially in the long run such as soil salinity, damage of drip tape during mechanical farm operation and clogging of emitters.

2.4.5.4 Sprinkler irrigation

This is the process of conveying water through pressured piping system through a nozzle. Piping system to convey the water, nozzles system and water sources under pressure are the basic components of sprinkler irrigation system. In this method, water is applied as a spray at a high velocity above the surface through sprinkle guns or nozzles. Water application almost resembles rainfall. The centre pivot system is the most recent class of sprinkler in use though several classes of sprinkler irrigation exist (Ali, 2010).

Sprinkler irrigation has made it technologically and economically possible to irrigate even too steep or uneven terrains as well as very sandy soils. However, its use is challenged in areas or hours of the day when, the wind speed is more than 12 km/h; as strong winds result in poor water allotment pattern (Hillel, 1987). Sprinkler irrigation is known to have problems of incidences of diseases from wetting of leaves. Only crops which do not have this problem like onions, chillies, maize and pigeon pea should be grown under sprinkler irrigation.

2.4.5.5 Drip/spot

The principle of drip/spot is to discharge small amounts of water, under low pressure, to relatively closely spaced emitters in plastic distribution pipes, placed on the soil surface (Franken, 2005). Water emission can be in the form of small drops, continuous drops, tiny streams, or diminutive sprays. Only a small part of soil is wetted, and the definite rooting volume is usually less than 50% of that of conventionally irrigated soil. The wetted area is kept continuously moist without being saturated (Hillel, 1987). Franken, 2005 has reported several classes of this type of irrigation.

The use of drip irrigation is very essential on saline soils (Karlberga et al., 2006; Hassanli ami Javan, 2005). Because of the high potential maintained in the root zone throughout the growing period, adverse effect on the crop from salinity are insignificant.Water with high salinity levels can therefore be used in drip than in other methods. The physical and chemical properties of soil, climatic parameters, irrigation management practices and crop's responses to salinity determine the suitability of water for irrigation (Oster and Wichelns,2003). One of the commonly used chemical parameters to evaluate water quality for irrigation is sodium adsorption ratio (SAR). Only water with a minimum SAR of 3.30 is considered as low sodium water hence suitable for irrigation with little harmful impacts on the crop (Katerji el al., 2003). At SAR levels of above 3.30, the water is considered to be of high salinity and therefore require special irrigation method as drip irrigation.

Precise water application guarantees minimum losses. In drip system, water application is deliberate hut recurrent; the volume of water applied is as close to the consumptive use of plants as possible. Slow rates of application ensure that water penetrates instantaneously downwards and sideways into the soil, reducing evaporation losses. Neither is there any significant runoff or percolation. The system is also espoused where the aim is to irrigate crops with irrigation water (Pereira et al., 2002).

Drip irrigation system has proven to be the best choice in production of high-value crops and those sensitive to leaves wetting. The greatest potential for drip irrigation is in situations where water is expensive or insufficient, for marginal soils, and for high-value crops. Crops such as tomato, tobacco, melon, brinjalsand other types of vegetables are prone to higher incidents of diseases resulting from wetting of leaves. For example, leaf spot, and blights in tomato; mildews in melon (Palti, 2012).

Since evaporation, deep percolation and runoff are diminished, thereby reducing water use efficiency,drip irrigation method is gradually the most efficient (Najafi and Tabatabaci, 2007). Efficiency as high as 80% have been reported. The volume of irrigation water applied via drip irrigation method is low compare to other methods of irrigation (Locascio, 2005).

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1. Study site

The study was carried out at KALRO Kiboko Research Centre, latitude 02° 127 S, longitude 37° 437 E, elevation 975 m above Sea level, and approximately 160 km southeast of Nairobi, the capital city of Kenya (Maingi et al., 2001).

The soils of the area are a suite of well-drained Fluvisols, Ferralsols, and Luvisols (USDA, 1997) soil classification. The soil texture is sandy clay loam with high drainage (Gichuki, 2000). Rainfall is bimodal, with the short rain in October– December and long rains from March–June (Gichuki, 2000). The mean annual rainfall is less than 500 mm (Juma, 2012).

The relief of the area is flat to gently undulating with a slope of 2%. The land use is a research site with a border cultivated area and abandoned trial site. The land is cultivated for field crops such as sorghum(*Sorghum bicolor*), maize (*Zea mays*), beans (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*) and pigeon pea (*Cajanus cajan*).

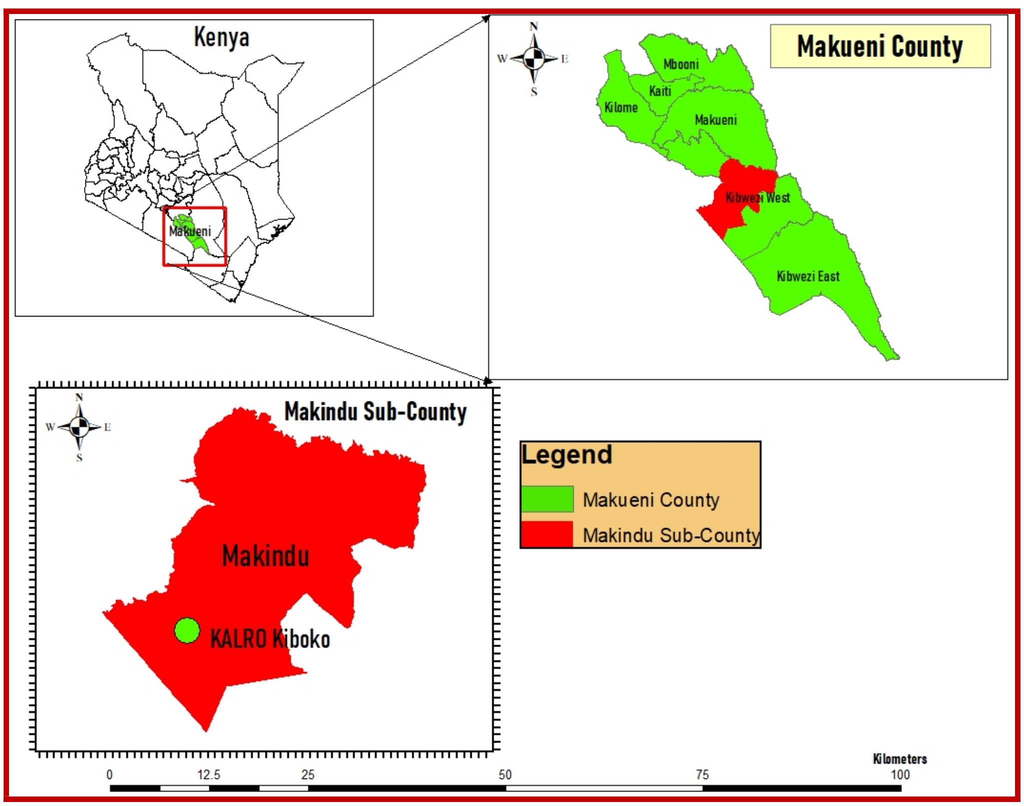

Figure 1. Map of Kenya showing the study site in Kiboko research station Makueni County; Source: Generated from ARC-GIS

3.2. Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments replicated three times. Four soil water deficit irrigation regimes were applied throughout the growing period, and rain-fed treatment acted as control.

Layout of the Experiment Plot and Drip Irrigation

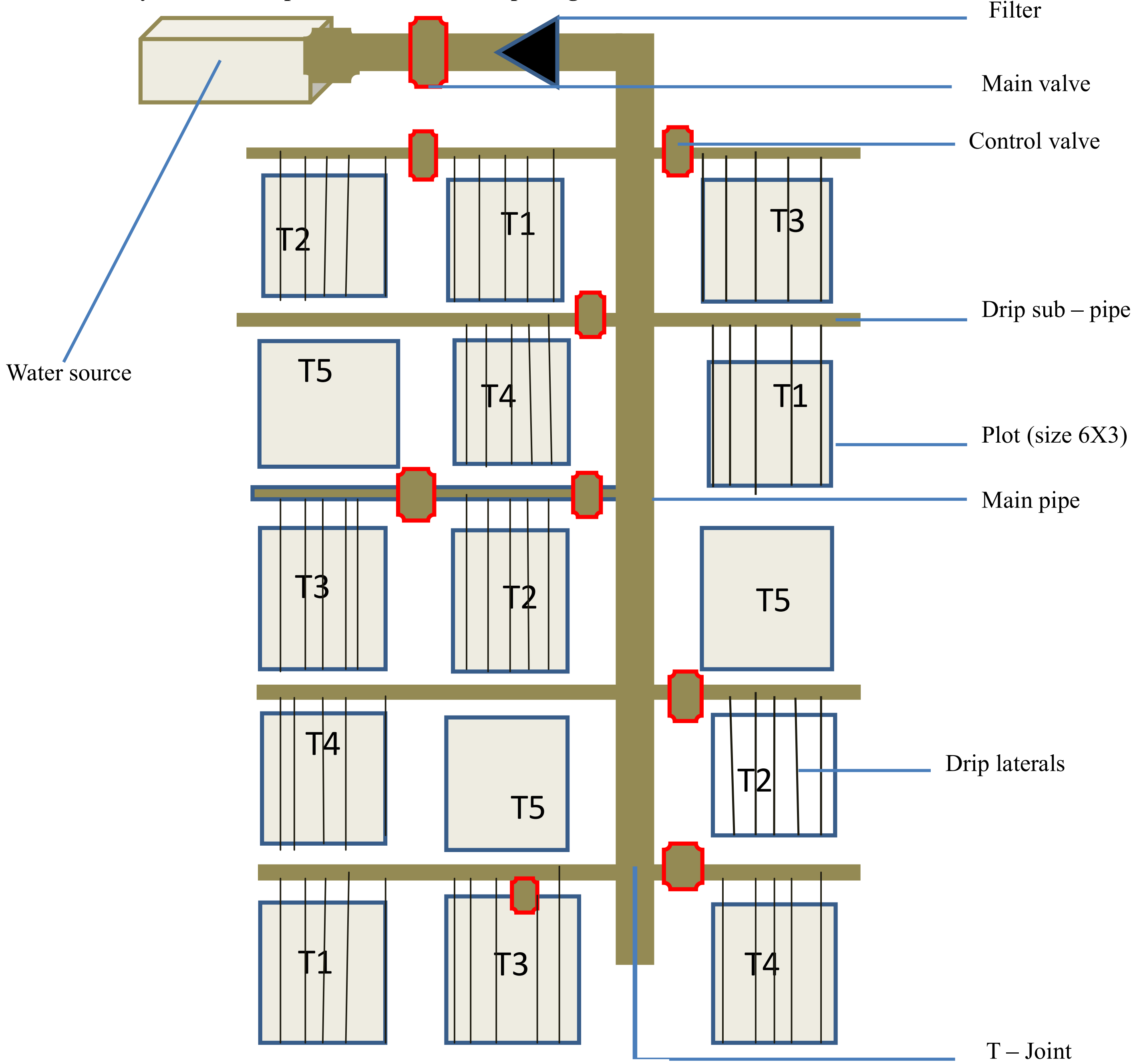

Figure 2. Layout of the experimental plot

The water regimes were T1 (100% FC), T2 (75% FC), T3 (50% FC) T4 (25%FC) and T5 (rain-fed) only rain-fed with no irrigation. Duma 43 maize variety was used as a test.

The experimental layout consisted of 15 plots of 6m x 3m ($18m^2$). The twelve (12) plots were irrigated while three (3) were under rain-fed. The total irrigated area was ($18m^2$ * 12) $216m^2$.

The water was applied by drip irrigation system and amount applied at each treatment was calculated from the full irrigation treatment (100%) using the maize crop water requirement's (CWR) at 100 cm rooting depth.

3.2.1. Drip irrigation installation

The system consisted of one filter, seven valves, T-joints, start connectors, Polyvinyl chloride (PVC) pipes, drip lines, end lines, and L-bow as figure 2. The treatments were irrigated individually and the water controlled by the use of valves in the system. The main valve controlled T1 since it was the last to go off during irrigation; while T2, T3, and T4 were controlled by individual valves. The duration of irrigation for each treatment was calculated from the system discharge per hour. Each plot had 5 drips laterals with 20 emitters per drip lateral with a spacing of 30cm between the emitters and 60cm between the drip laterals.The number of emitters per each plot was 100 and total number of emitters for entire irrigated area (12 plots) was 1200.

3.2.2. Christiansen's Coefficient of Uniformity (CCU)

Christiansen (1942) “defined” the coefficient of uniformity (CCU) as the ratio of absolute difference of each value from the mean and the mean of means. The Christiansen’s Coefficient of Uniformity (CCU) can be expressed as in Equ. 1.

$$CU = 100\left(1 - \frac{\sum_{i=1}^{n}|xi-\mu|}{\sum_{i=1}^{n}xi}\right) \qquad 1$$

Where,

n – Number of the depth measurements of the water applied, each representing an equal irrigated area

Xi – measured application depth in liters (L)

μ – mean application depths in liters (L)

CU – coefficient of uniformity (%)

The results obtained for uniformity test are shown in Table 1. The uniformity test was taken from 12 plots after complete installation of the drip irrigation system. Three drip laterals were selected in each plot from the edges and middle of the plot. Graded beakers in mm were placed in all the selected drip laterals in each plot to collect water during the testing process. The drip irrigation system was open to run for 10 minutes and stop, the water collected in the beaker was recorded, a mean value was obtained in each plot (Xi) and mean of means (μ) was obtained by the means (∑Xi/n) gotten from the 12 plots.

Table 1: Values for uniformity coefficient test in the field

n	Amount of water (ml) Xi	(Xi- μ)
1	163	22
2	172	13
3	180	5
4	181	4
5	183	2
6	188	3
7	188	3
8	190	5
9	190	5
10	192	7
11	195	10
12	196	11
n=12	∑Xi=2218	∑ |Xi - μ) =90

$\mu = (\sum Xi/n) = 185$ $\sum Xi = 2218 \sum |Xi - \mu) = 90$

$CU = 100[1 - (90)/(2218)]$

$\approx 96\%$

The coefficient of uniformity (CCU) was 96% which indicates almost equal distribution of all discharges from the emitters. Ascough and Kiker (2002) reported that the CU values (in %) for various irrigation systems varied from 17.4 to 95.2 per cent.

3.2.3. Distribution of uniformity (du) in the field

This is a confirmatory test on emitter discharge uniformity. Arranging the above data in ascending order, we obtain 163, 172, 180, 181, 183, 188, 188, 190, 190, 192, 195, and 196.

DU = Average of the lower quarter/the total average (Merriam and Keller, 1978)

= (163+172+180+183)/4 = 175.i.e. Average of the lower quarter = 175

DU = 100(175/185) = 95%

The confirmatory test on the emitter discharge uniformity obtained was 95%, which is an indication of equal discharge distributions in almost all the emitters.

3.2.4. Coefficient of variation (CV)

This is the ratio of actual emitter discharge (Q act) to the design emitter discharge (Q design) in litres per hour (LPH) given by Equ. 2.

CV= Q_act/Q_design ____ 2

Where Q.act=1.11LPH and Q design=1.2LPH

CV= 1.11 LPH/ 1.2 LPH

CV = 0.93

The coefficient of variation (CV) was 0.93 which indicate high accuracy of the emitters discharge efficiency, thus the variation between the system discharge and actual emitters was 7%. Similar coefficient of variation has been reported (Solomon, 1984; Burt et al., 1997; and Ascough & Kiker, 2002).

3.2.5. Determination of water application levels in the study site

Since the study used gravimetric method to determine soil moisture content;bulky density, rooting depth, plant population, effective irrigated area and discharge rate were used to calculate the volumetric water content required; Equ.3.

T1 (100 % to field capacity)

AW= FC – PWP = 23 – 11=12% by weight ________________________________3

AW = available water in the soil

FC = Field capacity

PWP = Permanent wilting point

Effective irrigated area = 216 m^2

Depth rooting zone DRZ= 100cm = 1m

Soil bulk volume = effective area * DRZ

Soil dry bulk density = 1.4g/cm^3

If 1cm^3 = 1.4g of soil

Vol. of soil is 216 m^2 by 1m, i.e. 216m^3, equivalent to, 216000litres, also equivalent to 216000000 cm^3 of soil

Then 216000000 cm^3 = 216000000* 1.4 = 302400000g

The FC of the soil is = 23% and AW = 12% = 120mm of water/m of soil

Gravimetric soil water content θg = volumetric soil water content/ bulk density

= 0.120/1.4 = 0.0857g/g

If 1g of soil contains 0.0857g of water

Therefore, 302400000cm^3 = 302400000* 0.0857= 25915680/1000

Seasonal water requirement [SWR] = 25915.68 liters

The entire growing season for Duma 43 maize variety into maturity is 120 days.

Average emitter discharge [qavg] = 1.1 lhr^{-1}

Therefore, the discharge for 1200 emitters = 1200* 1.1 = 1320 lhr^{-1}

Seasonal irrigation hours = 25915.68/1320 l/hrs. = 19.63 hours

Daily net irrigation water requirement (In) = 25915.68/120 days = 216 $lday^{-1}$

Daily gross irrigation water requirement Ig, taking into account application efficiency for the drip irrigation system as 95%

Ig = 216day^{-1}/0.95 = 227day^{-1}

The entire greenhouse will be subjected to 4water treatments, hence the water requirement per treatment is given as 227/4 = 56.75 l/day be consistent in expressions

In each replication, we have a total plant population of 100 plants base on the number of emitter plot or replicate, hence the water requirement per plant per day = 56.75 l/100 = 0.57 lday-1

Irrigation duration to achieve a AW of 12%

If 1.1l = 1 hour

Therefore 0.57 = 0.57/1.1 = 0.518 hours = 31 minutes

The same procedure was followed for 75, 50 and 25% at FC.

Table 2.Shows irrigation duration and amount of water applied per irrigation in each deficit irrigation regime. Full irrigation (100% FC) treatment obtained irrigation duration of 31 minutes and 0.57 liters of water per irrigation round, 23 and 0.43 in T2 (75% FC), 15 and 0.28 in T3 (50% FC) and 7 and 14 in T4 (25% FC) minutes and amount of water per irrigation round, respectively.

Table 2: Irrigation duration and amount of water applied per irrigation

Treatment/Replicates	Duration(minutes)	Amount water (litres)
T1(100%FC)	31	0.57
T1 (100%FC)	31	0.57
T1 (100%FC)	31	0.57
T2 (75%FC)	23	0.43
T2 (75%FC)	23	0.43
T2 (75%FC)	23	0.43
T3 (50%FC)	15	0.28
T3 (50%FC)	15	0.28
T3 (50%FC)	15	0.28
T4 (25%FC)	7	0.14
T4 (25%FC)	7	0.14
T4 (25%FC)	7	0.14

Legend T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity), and T5 (rain fed)

3.3. Agronomics Practices

Land preparation was done by ploughing and harrowing with a tractor and then subdivided into plots of 3m x 6m with a border spacing of 1m. Sowing was done at the onset of the short rains on 15thOctober 2018 – February 2019 for season (I), whereas Season (II) commenced from March 2019- July 2019. Planting was done manually at a spacing of 30cm between plants and 60cm between rows in each plot; two maize seeds were planted per hole. After germination, one seedling was thinned to obtain one plant per hole and a population of 55,556 plants ha^{-1}. Base on the analysis of chemical properties of the soil, 10tha^{-1} of well decomposed manure was applied through broadcasting and well mixed with the soil at land preparation. 012tha^{-1} of DAP was applied at planting time while 0.2tha-1 of calcium ammonium nitrate (CAN) was applied in two equal split applications at knee high and when plants were flowering. The weeding was done manually by had with an aid of hoe soon as weeds emerged throughout the cropping period. Random tagging of plants was done for accuracy and ease of monitoring growth and data collection. Pests and diseases were controlled upon incidence using chemical method. To manage armyworm, Emamectin Benzoate 19 EC at rate of 200ml per acre was sprayed to control the armyworm larva. Harvesting of maize was done at 120 days after sowing at the point when the grains are 14% moisture content. This was accomplished by hand picking and threshing.

Land preparation was done by ploughing and harrowing with a tractor and then subdivided into plots of 3m x 6m with a border spacing of 1m.

3.3.1. Maize parameters measured during the growing period

Growth parameters collected included plant height (cm), leaf area index (LAI), grains weight per 100 seeds (g), grain yield (tha^{-1}), total dry matter weight (tha^{-1}), and harvest index, Hi (%).

3.3.2. Plant height (cm)

Was recorded at 30, 60, and 90 days after emergency and at harvest for each treatment. The height readings were taken from the soil surface to the leave base of highest fully expanded leaf. Measurements were taken from five tagged plants per treatment using a meter ruler.

3.3.3. Leaf area index (LAI)

The leave length and width for the five tagged plants in each plot at the different water levels (T1, T2, T3, T4, and T5) was measured at the central part of the leaf at 50% heading.The leaflength and width were obtained for each plot, and the leaf area was calculated using (Watson D J. (1947) as Equ.4.

$$LA = L \times W \times 0.75 \qquad 4.$$

Where; LA= leaf area, L is the length 0.75 is the maize correction factor

The leaf area index (LAI) was estimated from leaf area per plant (A) divided by land area per plant (p) as Equ. 5.

$$LAI = \frac{\text{Leaf area per plant}}{\text{Land area per plant}} = \frac{A}{p} \qquad 5.$$

Where, LAI = leaf area index, A = leaf area per plant (cm^2) and P = land area per plant (cm^2).

3.3.4. Total dry matter weight (tha^{-1})

Total dry matter weight was recorded at harvest from five randomly selected plants per plot. The plant was separated from the plant's root portion, and then it was labelled and partially dried in before oven drying it at 60°C.

3.3.5. 100 seed grain weight (g)

One hundred grains weight was recorded from each plot from five randomly selected plants, and an average for the treatments. This measurement was done using a weighing machine.

3.3.6. Grain yield (tha^{-1})

Grain yield in tha^{-1} from each plot was recorded from air-dried cob, separated and cleaned before drying it to 14% moisture content. The grains were weighed and recorded in kilo grams (kg) before it was converted to tha^{-1}.

3.3.7. Harvest Index (%)

This refers to the crop's economic yield divided by total dry weight, as Donald (1992) described. He used the formula below to calculate the harvest index as Equ. 6.

$$\text{Harvest index} = \frac{\text{Grain yield (kilo gram per hectear)}}{\text{Total dry weight (kilo gram per hecte)}} \qquad 6$$

3.4. Measurements of soil moisture and evapotranspiration

Soil moisture content was monitored at a depth of 30, 45 60, 75, 90, 105, and 120 cm weekly using the gravimetric technique.

A soil sample was collected at each plot using a soil auger, and the sample was weighed before oven drying at 105 0C for 24 hours to constant weight.

Soil water balance equation was used to estimate the evapotranspiration (ETo) (Miranzadeh et al., 2011; Karuku et al., 2011; Karuku et al., 2014; Koech et al., 2015, Kiplangat et al., 2019). Equ.7.

$$ET = (P + I + SG) - (D + R) - \Delta S \qquad 7.$$

Where, ET= evapotranspiration (mm), P= precipitation (mm) taken from nearby meteorological station, I = Irrigation water (mm) applied, D = deep percolation (mm), ΔS = changes in soil moisture content (mm), R = runoff and SG = the groundwater contribution to plant available water (mm)

D, SG and R was found to be negligible(how?) during the experimental period, hence the equation was rewritten as Equ. 8.

$$ET = P + I - \Delta S \qquad 8.$$

3.4.1. Water Use Efficiency (WUE)

Was estimated from the yield in kilogram (kg) and actual maizeevapotranspiration (ET_{maize}) (mm) with (Karuku et al., 2014, Araya et al. 2011, Song et al, 2019)Equ. 9.

$$WUE(kgha^{-1}mm^{-1}) = \frac{\text{Yield (kg ha}^{-1})}{\text{ETmaize (mm)}} \qquad 9.$$

Where,

WUE is water use efficiency (kgm^{-3}), Y is the maize yield (kg ha^{-1}), and ET_{maize} is the actualmaize evapotranspiration.

3.5. Data analysis

The data analysis was done with the aid of GenStat 19th edition (Lane and Payne, 1997) and subjected to analysis of variance (ANOVA) with means differences separated by Duncan's multiple range test at 95% confidence level (P≤0.05 level of significance).

CHAPTER FOUR

Effect of deficit irrigation regimes on maize (*Zea mays*) growth, yield, and water use efficiency in the semi-arid area of Kiboko, Kenya

Abstract

Background information: Water scarcity isa major problem affecting agricultural production worldwide, and therefore, increasing its effectiveness becomes paramount. ***Methodology:***A study was carried out for two seasons in Kiboko, Makindu Sub-County during short rains of 2018 and long rains of 2019 to evaluate the response of maize growth, yield, and water use efficiency to regulated deficit irrigation in semi-arid area of Kiboko. The experiment was laid out in Randomized Complete Block Design with three replicates. The treatments were T1 (100 % field capacity), T2 (75 % field capacity, T3 (50% field capacity), T4 (25 % field capacity), and T5 (rain-fed) were evaluated. ***Results:***In season I, there was a significant difference ($P \leq 0.05$) on Plant height, LA, and LAI, in T1 compared to T5. Significant difference ($P \leq 0.05$) in plant height were recorded in T1 that was 308.1cm compared to T5 (control) at 263cm height. Deficit irrigation showed a highly significant ($P \leq 0.05$) effect on maize growth in season II, with plant height of 270.3cm in T1 compared to 95.6cm height in T5. The yield components showed significant difference ($P \leq 0.05$) on cob-size, 100grains weight, aboveground biomass and HI in both seasons. The highest yield of 10.9 and 10.2 tha^{-1} was obtained in T1, season I and II followed by T2, T3, T4. T5 had the lowest yield of 8.8 tha^{-1} and 3.0 tha^{-1} in the season I and season II, respectively. Higher aboveground biomass and yield were obtained under full irrigation, thoughbiomass and yield declined under varied regulated deficit irrigation regimes. WUE had no significant difference in the season I, since rains were moderately reliable, thus allowing pausing of irrigation with little water stress to the maize crop. However, in season II, significant difference ($P \leq 0.05$) in WUE was observed. Generally, WUEranged from 19.6 to 22.kg ha^{-1} mm^{-1} in season I and 16.6 to 24.8 kg $ha^{-1}mm^{-1}$ in season II.***Conclusion:***Growth and yield of maize increased with increased amount of irrigation water and decreased under reduced irrigation while WUE increased with reduced irrigation throughout the season and decreased under sever water stress. ***Implication***: Irrigating maize at 50% water deficit increased WUE with minimal yield decline, hence a better DI strategy in water conservation under scarcity situation.

Keywords: Regulated deficit irrigation, performance and yield, water use efficiency, water stress.

4.1. Introduction

Regulated deficit irrigation (RDI), a concept coined in the 1970s, controls soil water deficit at certain times in a season to reduce irrigation (Stewart and Steiner, 1990) water requirements. This practice has shown grain yield substantially increased during the last decade. The rapid decline of water resources in recent years, however, has led to an urgent need for a reduction of irrigation to make agriculture sustainable in Kiboko semi-arid area (Kang et al., 2002; Kipkorir et al., 2001).

By 2027, global cereal consumption is expected to rise by 14%, owing to increased food and feed consumption in developing countries(OECD/FAO, 2018). Maize consumption is predicted to rise by 16 percent by 2027, with maize used for animal feed accounting for 58 percent of total use in 2027, owing to rapidly growing livestock industries, rising incomes in most developing nations, and strong demand for meat and poultry consumption(Locke et al, 2013). Maize for human consumption will grow mostly in emerging countries, particularly in Sub-Saharan Africa, where populations are fast increasing and white maize is a staple in several countries(OECD/FAO, 2018).

Deficit irrigation (DI) systems are among the climate smart adaptations that have been successfully implemented for various crops (Tari, 2016; Afshar et al.,2014; Zhang et al., 2016). Drought stress is induced incrops by withholding irrigation at specific growth phases or limiting irrigation water application, either for a specific period or throughout the growing season.As a result, crops cultivated under DI receive a limited amount of water below their full requirements, which boosts irrigation water use efficiency under ideal conditions(Chai et al., 2016, Liu et al., 2013, Huang et al., 2005). The yield penalty could economically be tolerable compared with the cost or value of water saved in water-limited environments. several researchers have found out that DI maximizeswater use efficiency, thereby increasing yield per unit water used (Chuanjie et al., 2015; Cakir 2004; Aguilar et al. 2007; Jahansouz et al., 2014; Domínguez et al., 2012).

In Kenya, DI has been brought about by the increase in population, migration into the Arid and Semi-Arid Lands (ASALs), and climate change (Kinama et al., 2007) and variability. Rainfall variability throughout and among seasons has resulted in moisture deficiencies in Kenya's ASALs.

Due to predicted temperature rises, climate change increases soil evaporation and limits water availability to crops.In semi-arid locations, soil evaporation can account for up to 50% of total rainfall in the soil water balance.(Kinama et al., 2005).

4.2. Materials and Methods

As outlined in chapter three sections 3.1 to 3.9.

4.3 Results and Discussion

4.3.1 Soil characterization

4.3.1.1Soil chemical properties

The soil chemical properties of the experimental site are presented in Table 3. The soil pH-H_2O obtained was 7.5, which is within the required pH for effective maize growth that ranges between, 5.0 to 7.0 (FAO, 2012).

Table 3: Chemical soil properties of the experimental site

Parameters	Soil characterization	Very high	High	Medium	Low	Very Low
pH-H2O (1:2.5)	7.5		>7	5.5-7	<5.5	-
CEC (me 100g-1)	15.4	>40	25-40	12_25	6 – 12	<6
OC (%)	1.1	-	>2.5	1.5-2.5	<1.5	-
TN (%)	0.1	-	>0.7	0.5-0.7	<0.5	-
Av P (ppm)	51	>46	26-45	16-25	10 _15	<9
Exch K (me 100g-1)	0.88	>1.2	0.6-1.2	0.3-0.6	0.2-0.3	<0.2
Exch Ca (me 100g-1)	2.4	>20	10_20	5_10	2 – 5	<2
Exch Mg (me 100g-1)	3.3	>8	3_8	1_3	0.3-1	<0.3
Exch Na (me 100g-1)	0.53	>2	0.7-2	0.3-0.7	0.1-0.3	<0.1

Legend: TN – Total Nitrogen, OC – Organic carbon, P – phosphorous, K – Potassium, Ca – Calcium, Mg – Magnesium, Na – Sodium, CEC – Cation Exchange Capacity,

Soil organic matter content (% OM) was 1.9%, (1.72X1.1) which is low in the soil. According to (USDA, 1997) soils with organic matter content of less than 3% is considered not suitable for crop growth without addition of fertilizers and manure application and soil organic matter content ≥ 6% is the ideal quantity for good soil. Initial available Phosphorus (P) content was 51 ppm. Available phosphorus (P) content was high since soil with an extractable Phosphorus content of≥20 ppm is suitable for crop growth (USDA, 1997), hence the soil does not require the application of P fertilizer.

Initial exchangeablecalcium content (Ca) was 2.4 me $100g^{-1}$, which shows a low content (Benedict et al., 2018). Calcium content ≥20 me $100g^{-1}$ is high, 5 – 10 is moderate while 2 – 5 me $100g^{-1}$ is low hence the addition of calcium through fertilizer is required.

Initial exchangeable magnesium (Mg) content is 3.3 me $100g^{-1}$ which represent a moderate content of magnesium in the soil asit lies between 3-8me $100g^{-1}$, hence the addition of Magnesium through fertilizer is not required.

Initial exchangeable potassium (K) of 0.88 me $100g^{-1}$ range between 0.6-1.2 me $100g^{-1}$ which indicate a high content of potassium in the soil (Gebrekidan, H., & Negassa, W, 2006), hence the soil is rich in exchangeable potassium (K).

4.3.1.2 Soilphysical properties

One profile pit was dug out in the field and undisturbed soil samples obtained from different horizon depth using a core ring to determine the soil physical properties of the soil. The samples were used to determine the soil water content (SWC), dry bulk density ($_{\rho}b$), total porosity, and total soil water potential. Saturated hydraulic conductivity, Ksat was also determined using the constant head method as described by Reynolds and Elrick (2002). Soil water retention was set for pF determination with ceramic plates pressure plates at pF0.0, 2, 2.3 2.5, 3.7 and 4.2 as described by Schofield (1935)

Soil water content measurement

Soil wetness was measured in the core rings using the gravimetric approach as the ratio of the volume of water in the soil sample to the dry weight of the soil, after oven - drying at 105 °C for 24 hours and then using Equ.10, 11, and 12.

$$\%\ \theta g = \frac{Mw - Md}{Md} x100 \qquad 10$$

Where: Mw = Weight of fresh wet soil Md= weight of oven-dry soil

$$Volumetric soil water = Gravimetric soil moisture \times bulk density$$

$$Water storage in a\ horizon\ (mm) = \frac{Volumetric\ X\ Soil\ depth}{10} \qquad 11$$

The capacity of soil to retain water and avail to crops after rainfall was computed as TAW (total available water). It's a measure of the quantity of water a crop extracts from its rooting zone as shown in Equ.12.

$$TAW = 1000(\theta FC - 0.55\theta PW)\ (mm) \qquad 12$$

Where; TAW as the quantity of water in the root zone(mm); Zr representing the rooting depth (m); θ FC; field capacity(m^3m-^3); θ PWP permanent wilting point (m^3m^{-3}).

Readily available water (RAW) indicates the fraction of total available water in which a crop can extract devoid of stress (Karuku et al., 2012). RAW was computed by Equ. 13.

$RAW = (mm)$ ____13

Where

p represents the average available water index (TAW) that can be exhausted from the before the reduction in ET. Most crops p ranges between 0-1. For the maize (field corn), the p was 0.55. However, p is only applicable when ETc= 5mm/day. In situations where ETc >5mm/day, p was given by Equ. 14.

$p = (0.55) + 0.04\ (5 - ETc)$ ______________________________________14

The soil physical properties of the study site are shown in Table 4.

Table 4: Physical soil properties of the experimental site

Soil depth (cm)	Texture %Sand	%Clay	%Silt	Class	Bulk density (gcm^{-1})	FC (Vol. %)	PW (Vol. %)	AWC (V0l. %)	Ksat (mm day^{-1})
0 – 15	70	24	2	SCL	1.3	22.13	10.54	11.59	71
15 – 30	70	24	2	SCL	1.35	22.85	11.12	11.73	63
30 – 45	68	28	4	SCL	1.41	23.01	11.22	11.79	68
45 – 60	68	28	4	SCL	1.42	23.42	11.41	12.01	62
60 – 75	68	28	5	SCL	1.43	23.51	10.86	12.65	58
75 – 90	68	28	8	SCL	1.43	23.62	11.24	12.38	63
90 – 105	68	28	8	SCL	1.55	22.73	11.42	11.31	60
Average	68	27	5	SCL	1.4	23	11	12	64

Legend: SCL – Sandy Clay Loam FC – Field Capacity, PWP – Permanent wilting Point, AWC – Available water content, Ksat – Saturated hydraulic conductivity

The sandy soil content was 68, clay 27 and the silt soil content shows low soil contain of 5%, thus the textural class of the soil was sandy clay loam according to the textural triangle. The bulk density indicated a slight variation with depth and ranged from 1.30 gcm^{-3} at the 0 – 15 cm to 1.55 gcm^{-3} at the depth of 90 – 105 cm. This could be because of decrease in organic matter content with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The soil moisture content at field capacity and permanent wilting point was at pF 4.2 and PWP 2.0, respectively and the hydraulic conductivity Ksat ($mm.day^{-1}$) was high which indicated high permeability of the soil.

4.3.2 Climatic data

Average monthly climatic data is shown in Table 5. Maximum and minimum air temperature (^{0}C), rainfall (mm), relative humidity (%), wind speed (ms^{-1}) at screen height 2m about the ground and sunshine hours were obtained from Kiboko research station.

Table 5: Mean climatic parameters during the two growing seasons

Cropping Season	Year	Month	Tmax (^{0}C)	Tmin (^{0}C)	Wind speed (ms^{-1})	Sunshine ($Hday^{-1}$)	RH (%)	Rainfall (mm)	ETo (mm)
		Sep	30.78	15.22	207	7.93	79.6	0.30	4.7
		Oct	30.53	17.27	216	7.23	82.6	1.43	4.9
Season I	2018	Nov	31.46	18.01	173	6.06	82.0	5.73	4.2
		Dec	29.93	17.98	229	6.07	85.3	10.4	3.7
		Jan	31.40	17.37	138	7.05	79.3	1.39	4.2
		Fed	33.13	17.13	155	7.46	82.8	0.00	4.8
		Mar	33.13	17.12	164	6.87	77.2	0.00	4.7
Season II	2019	Apr	35.10	19.13	219	6.59	72.4	1.36	4.1
		May	30.53	17.45	138	6.79	80.4	0.44	3.8
		Jun	29.30	15.00	138	6.92	79.3	0.06	3.5

Legend: T_{max} (^{0}C) (maximum temperature), T_{min} (^{0}C) (minimum temperature) RH (relative humidity)

The mean air temperature in season I (September – December 2018) was 30.8^{0}C max and 17.2^{0}C min. The hottest month was November with a mean air temperature of 31.5^{0}C max and 18^{0}C min. In season II (February – June 2019), the mean air temperature was 32^{0}C max and 17.2 ^{0}C min with April as the hottest month with a mean temperature of 35 ^{0}C max and 19.1 ^{0}C min. The temperatures were within the range (21 to 27 ^{0}C) for optimal maize growth (Sanchez and porter, 2014). The average rainfall in season I was 3.9 with the highest rainfall of 10.4 mm recorded in December and the lowest of 1.4mm in October. Season II had 0.37mm as its average rainfall which indicate a low rainfall in both seasons though higher in season I than in season II. Rainfall occurrence depends greatly on the temperature and weather conditions (Trenberth, 2011, Mawonike and Mandonga, 2017). A high temperature increases the rate of potential evaporation which would deplete the soil moisture content (Bushand and Brandsm, 1999; Nkuna and Odiyo, 2016). Relative humidity (RH) on average was 82 and 78% in season I and II, respectively which moderately high. Relative humidity (RH) has a direct impact on plant water relations and has an indirect impact on leaf growth, photosynthesis, pollination, disease occurrence, and, ultimately, economic production(Hoogenboom, 2000). Through stomatal regulation and leaf water potential, the saturation deficit (100-RH) that indicates the dryness of the atmosphere inhibits dry matter production (Grange and Hand, 1987). The wind speed was 192 and 163 ms^{-1} in season I and II, respectively whereas sunshine recorded an average of 6.9 hours in both seasons.

4.3.3 Maize growth parameters

Maize growth parameters recorded include; plant height (cm), leaf area and leaf area index are shown in Table 6.

4.3.3.1 Maize height (cm)

Maize height was not significantly affected by DI (T1, T2, T3 and T4) in season I. However, a significant difference (P≤0.005) was observed between T1 (100% FC) at 308 cm and T5 with 263 cm maize height at the maturity stage. The is in agreement with Rosadi et al. (2005) who found out that a small difference in moisture deficit levels did not affect plant height.

Table 6: Effect of deficit irrigation on growth parameters of maize

Cropping Season	Treatments	Maize Height (cm)	Leaf Area (cm^2)	Leaf Area Index
Season I	T1	308a	718a	4.8a
	T2	297a	707a	4.7a
	T3	295a	673a	4.5a
	T4	292a	667a	4.5a
	T5	263b	661a	4.4a
Season II	T1	306a	700a	4.6a
	T2	262b	591ab	3.8b
	T3	225c	540b	3.3bc
	T4	197d	525b	2.9c
	T5	96e	242c	1.2d

Legend T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity), and T5 (rain-fed). Mean followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

In season II, maizeheight had highly significantly (P≤0.005) difference between deficit irrigation regimes and rain-fed, with a maximum maize height of 306 cm obtained in T1 followed by 262 in T2, 225 cm in T3, 197cm in T4 and the least maize height of 96 cm was recorded under in T5. Water is an important component of plant cell and raw material for photosynthesis. Carbohydrates are manufactured from water combine with carbon dioxide (CO_2) in the presence of sunlight. Water keeps the plant turgid and erect; moisture deficiencies in maize result in cell flaccidity and the plant drops and wilt. Tari (2016) and Jia et al. (2017) found out that maize plant grown under sufficient moisture content produce high plant height while water stressed condition produces dwarf maize plant.

4.3.3.2 Leaf area and leaf area index

The data obtained in season I revealed non-significant difference in leaf are and leaf area index among the deficit irrigation treatments (T1, T2, T3 and T4).However significant difference was noted in fully irrigated (T1) treatment with 718cm and 4.8 leaf area and leaf area index compare 661 cm and 4.4 obtained in rain-fed condition.Pandey et al. (2000) recorded the highest value of leaf area index for corn under full irrigation (without stress). In season II DI had high significant ($P \leq 0.005$) effect on the maize leaf area and leaf area index. A maximum leaf area and leaf area index of 700cm and 4.6 was recorded in T1 followed by 591 and 3.8 in T2, 540 and 3.3 in T3, 525 and 2.9 in T4 and the least leaf area and leaf area index of 242cm and 1.2 was observed under rain-fed (T5). The findings were in agree with Bouazzama et al.(2010) who found out low leaf area index in the treatments under more water stress.

4.3.4 Maize yield components

Yield attributes of maize measured during the harvesting includes; cob size (cm), grain weight per 100 seeds, aboveground biomass, yields and harvest index (HI) are shown in Table 7.

4.3.4.1 Maize cob size (cm*)*

The data on maize cob size obtained in season I hasshown a significant effect of deficit irrigation on maize cob size. Among the deficit irrigation regimes, the maximum cob size of 19.6cm was observed in T1 which was no significantly ($P \leq 0.05$) different from its immediate irrigation regimes of T2, T3 and T4. Whereas the minimum cob size of 18.1cm was obtained in T5, this was significantly ($P \leq 0.05$) difference compare to the irrigated treatments. In season II deficit irrigation had a high significant effect on cob size, with highest cob size of 19.9cm obtained in full irrigated treatment (T1) followed by T2 (75% FC), T3 (50% FC), T4 (25% FC) and least cob size of 13.2cm was recorded under rain-fed (T5).

Table 7: Effect of deficit irrigation regimes on yield components of maize

Cropping Season	Treatments	Cob size (cm)	g-w/100 (g)	Biomass (tha^{-1})	Yield (tha^{-1})	Harvest index
	T1	19.6a	39.6a	35.2a	10.9a	0.31a
	T2	19.4ab	38.4a	33.9a	10.4a	0.30a

Season I	T3	19.2ab	37.8ab	32.7ab	9.8ab	0.29ab
	T4	18.6ab	37.2ab	30.4b	9.0b	0.29ab
	T5	18.1b	33.6b	28.1c	8.4c	0.29ab
	T1	19.9a	41.3a	33.8a	10.2a	0.30a
	T2	17.1b	40.8a	30.3b	9.1b	0.30a
Season II	T3	16.9bc	39.9a	27.6c	8.3bc	0.29ab
	T4	15.7c	35.1b	23.9d	6.0c	0.25b
	T5	13.2d	18.1c	14.8e	3.0d	0.20c

Legend: T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity), and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

4.3.4.2 Grain weight per 100 seeds

Deficit irrigation regime had significant (P≤0.05) effect on 100 seed maize grain weight (g). in season I, with a maximum of 39.6g recorded in T1 but had no significant effect compared to T2 while T3, T4 and the rain-fed that recorded least grain weight of 33.6 g was significantly (P≤0.05) different. In season II grain weight showed significance difference, among the DI regimes.A maximum grain weight of 41.3g was obtained under full irrigation (T1) that had no significance deference compared to T2 and T3, though a significant (P≤0.05) difference was noted in T4 and T5 that obtained 35.1g and 18.1g respectively compared T1. Grain filling stage require adequate moisture content to facilitate the assimilation of dry matter to the grains, hence water stress at this stage will reduce this assimilation. Water stresscause the production of sterile pollen grains thus low grain weight (Mohammad, et al, 2020, Du et al. 2015, Linker et al. 2017, Mohammad et al. 2017 and Li et al. 2018) found that water stress in reproductive stage reduces grain weight of maize.

4.3.4.3 Above ground biomass (tha^{-1})

Was found to be linear with deficit irrigation. The data in season I, revealed a significant effect (P≤0.05) of DI on above biomass, a maximum above ground biomass of 35.2 tha^{-1} was recorded in T1 which was no significance difference from to 33.9tha^{-1} obtained from T2, but significance difference to T3, T4 and T5 that obtained the minimum above ground biomass of 28.1tha^{-1}. In season II deficit irrigation had high significant effect on biomass accumulation, with a maximum of 33.8tha^{-1} recorded in in T1 followed by T2, T3, T4 and T5 that obtained the least biomass of 14tha^{-1}. Generally, accumulation of above ground biomass of maize depends on the level of deficit irrigation regime and it reduces significantly with decrease in deficit irrigation. Henry E et al, (2008) found out that DI resulted in reduction of both biomass and grain output during the growth period.Irrigation considerably boosted maize dry matter and grain output, whereas DI significantly decreased maize crop production.(Yazar et al., 1999 and Pandey et al., 2000).

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4.3.4.4 Grain yield (tha^{-1})

Maize grain yield was significantly (P≤0.05) affected by DI regimes. In season I the data collected revealed a maximum grain yield of 10.9tha^{-1} obtained in T1 which was no significantly difference from T2 but significantly (P≤0.05) different T3, T4 and T5 that record the lowest grain yield of 8.4tha^{-1}. In season II maximum yield 10.2tha^{-1} was obtained in full irrigation (T1), 9.1tha^{-1} in T2, 8.5t ha^{-1} in T3, 6.0 tha^{-1} in T4 and lowest yield of 3.0tha^{-1} was obtained in rain-fed. Season I have low yield variation between DI and rain-fed condition whereas season II has high yield variation between irrigated and rain-fed, theses could be as result of rainfall pattern between the two seasons. Season I slightly moderate rainfall that had added significant moisture content to the soil compared to season II that received very little rainfall (Table 5), hence the crop was mostly depending on irrigation thus the effect of DI and water stress cause the yield variation in season II. The result clearly shows that maize yield is linear with DI regimes, which is in agreement with the findings of Naescu (2000), Karam et al. (2003), Panda et al. (2004), Mengü and Ozgurel (2008)and Oktem, (2008) who reported that DI reduces the yield of maize crop, and maize dry matter increases significantly with irrigation. The findings are similarly consistent with those of Rhoades and Bennett (1990) and Lamm et al. (1995), who stated that planning DI for maize without reducing yield is challenging.

4.3.4.5 Harvest index (HI)

The maize harvest index was almost the same in season I (Table 6). However, in season II harvest index revealed high significant (P≤0.05) difference, with high harvest index obtained in T1 and T2 which was highly significant (P≤0.05) to 0.29 recorded in T3, 0.25 in T4 and 0.2 in T5 as the least harvest index. Yield and above ground biomass in season I were moderately high along with a small variation among all the treatment, which results to low variation in harvest index in season I. The maximum harvest index of maize was obtained when the field was well irrigated as observed elsewhere by other workers (Golzardi et al., 2017; Mohammadi et al., 2017 and Xue et al.,2018).Water stress lowers yield via lowering biomass accumulation and the harvest index (Bryant et al., 1992).Water deficit, on the other hand, only affected the harvest index when stress was imposed during anthesis (Traore et al. 2000).

4.3.5 Water use efficiency by maize crop

The effects of DI on water use efficiency of maize are shown in Table 8. Water use efficiency of maize was significantly ($P \leq 0.05$) different and varies with seasons and irrigation level. The values recorded for water use efficiency of maize rangedfrom 16.6 to 24kgha^{-1}mm^{-1}. In season I, the maximum water uses efficiency of 22kgha^{-1}mm^{-1} obtained under rain-fed (T5), which was significantly ($P \leq 0.05$) difference compare to 19.7 and 19.6kgm^{-1}mm^{-1} obtained in T1 and T2, respectively.

Table 8: Effect of deficit irrigation on maize water use efficiency (kgha^{-1}mm^{-1})and ET_{maize}

Cropping Season	Treatments	ET_{maize} (mm)	WUE (kgha^{-1}mm^{-1})
Season I	T1	553a	19.7b
	T2	530a	19.6b
	T3	495b	19.8ab
	T4	447c	20.6ab
	T5	401d	22.0a
Season II	T1	445a	23ab
	T2	377b	23.7ab
	T3	334c	24.8a
	T4	303d	19.8bc
	T5	180e	16.6.3c

Legend T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity), and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at ($P \leq 0.05$) level.

The slight significance differences observed between DI treatments in the first season could be the fact that there was a sufficient amount of rainfall that gave almost negligible supplemental irrigation during the growing period. Howell, (2001) found out increase WUE with decline in irrigation.

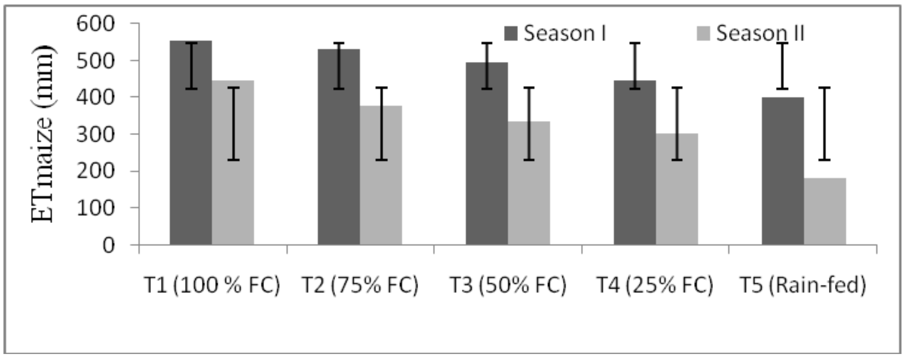

Figure 3: ET_{maize} (mm) versus deficit irrigation regimes

In season II, WUE was significantly ($P \leq 0.05$) different among treatments, with a maximum of 24.8kg $ha^{-1}mm^{-1}$ obtained in T3 followed by T1 and T2 that recorded the same water use efficiency of 23.7kg$ha^{-1}mm^{-1}$, 19.8 obtained in T4 and lowest was 16.6kg $ha^{-1}mm^{-1}$ recorded under rain-fed (Figure4). Rainfall was insufficient and unreliable in season II; as a result, the crop (maize) was entirely dependent on irrigation.

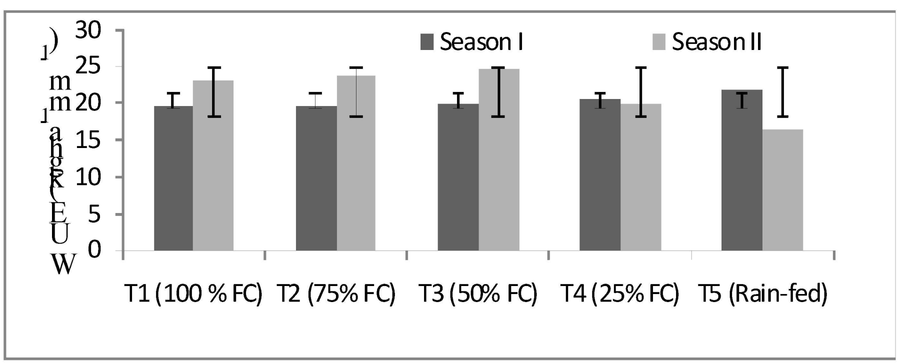

Figure 4: Water use efficiency (kg$ha^{-1}mm^{-1}$) of maize versus deficit irrigation regimes

By adjusting irrigation quantities, the RDI keeps crop plants under water deficitstress throughout certain growth stages.The stomata of thoroughly irrigated plants are normally totally open.Plants open their stomata to absorb CO2 and obtain carbon, but they also lose a lot of water in the process (Kang and Zhang, 2004). The stomatal opening can be narrowed somewhat to prevent water loss while having no influence on photosynthetic rate.Earlier studies suggested that plants had the ability to enhance their WUE in this fashion, increasing their chances of surviving a drought while minimizing carbon gain and biomass accumulation; however, this could only happen if crops are aerodynamically well connected to the atmosphere (Cowan, 1988; McLaughlin and Boyer, 2004).

4.3.6 Conclusions

Generally irrigating maize (*Zea mays*) under DI in the study area will have the following effect on its productivity;

- Irrigating maize at 50% water deficit would improve WUE without much reduction in yield.
- High maize performance along all the DI regimes in season I was due to slightly moderate rainfall, while season II where having very little and unreliable rainfall hence deficit irrigation where not pause.
- Deficit irrigation under 25% field capacity (FC) reduces yield and WUE

CHAPTER FIVE

Use of AquaCrop model to evaluate and predict climate change impact on maize (Zea mays) performances in the semi-arid area through simulation of deficit irrigation regimes in Kiboko Kenya.

Abstract

It is projected that climate change will impact water sources and agricultureseverely in the future. However, the effect will vary according to various agro-ecological zones. This simulation study was carried out to predict the impact of climate change on maize (*Zea mays*) yield under DI regime, especially in arid and semi-arid areas such as Kiboko. AquaCrop model version 6.0 was used to predict yield of maize under baseline climate (1986-2005) and two future climate changes of 2020-2039 and 2040-2059 under the Relative Concentration Pathways (RCP) 4.5 and 8.5 scenarios. The model was first calibrated based on two seasons of maize yield in Kiboko under five deficit irrigation regimes, namely; T1 (100% field capacity), T2 (75% field capacity), T3 (50% field capacity), T4 (25% field capacity) and T5 (rain-fed) which acted as the control. The forecasted maize yield ranged from 1.4 in the rain-fed to 12.0 tha^{-1} in fully irrigated (T1) for both 2020-2039 and 2040-2059 climate scenarios, compared to 0.64 and 12.0tha^{-1} in the baseline. Net irrigation requirement (NIR) ranged from 71mm in T4 to 280mm in T1 for2020-2039, which indicate a decrease of 8.5 and 18% compared to 77 mm and 332mm in the baseline while 2040-2059 climate scenarios showed

18.5 and 50% decrease in NIR. The future WUE under climate scenarios 2020-2039 will range from 7.4kgha^{-1}mm^{-1} for rain-fed to 27.4kgha^{-1}mm^{-1} under T1 while climate scenarios 2040-2059 will record 4.0kg ha^{-1}mm^{-1} to 29kgha^{-1}mm^{-1} for T5 and T1, respectively. The use of 100% soil surface cover withmulch will positively impact yield, WUE, and NIR. 100% soil surface mulching was predicted to increase the yield of maize significantly ($P \leq 0.05$) by 2.5, 23 and 30% in T1, T5, and under the rain-fed condition for both climate scenarios 2020-2039 and 2040-2059 under RCP4.5 and 8.5, respectively while WUE will significantly increase by 4.9 to 9.5% under DI in both climate scenarios. In contrast, WUE under rain-fed conditionsranges from 16.4 to 141% for both climate scenarios, while NIR significantly reduced by 7.6 and 27% under RCP4.5 and RCP8.5 climate scenarios compared to 7.9% and 10.5% in the baseline.

5.1 Introduction

The availability of quality water for use in irrigated agriculture is greatly affected by change in land use, climate change, population growth, and increasing demand in industrial and domestic uses. Producing more food with less water is a global problem for agriculture, amid growing concerns that water scarcity and food poverty are among the most important issues confronting many nations in the twenty-first century(Toumi et al., 2016). Crop yield focusing on predicting crop water productivity (WP), such as DI and crop simulation modelling are among the water management strategies that play an essential role in the establishment of a sustainable water supply. DI management technique contributes to reducing irrigation water waste, according to extensive studies and publications. (Kuscu and Demir, 2012).

Climate warming, according to the Intergovernmental Panel on Climate Change (IPCC), might result in a 20 percent drop in prospective agricultural yields due to an increase in surface temperature and a decrease in water availability for agriculture, especially in subtropical land regions(IPCC, 2007). Climate change has an impact on rain-fed agriculture activities and practices in general, particularly in nations that rely on rain-fed agriculture, such as Kenya (Karuku et al., 2014a).Due to climate change, Kiboko, Makuen County is in a semi-arid environment with minimal, inconsistent, and unreliable rainfall. (Mango, 1999; and Herrero et al., 2010).As a result, through yield forecasting, it is necessary to design climate change adaptation and mitigation techniques for agriculture production. Until recently, crop yield estimations were based solely on empirical data (Ichami et al., 2019).Crop growth simulation models, such as AquaCrop, have been used to better understand the effects of genotype, soil types, and management tactics on crop development, as well as to analyze the impact of climate change on agriculture (Karuku et al., 2014b; Karuku and Mbindah, 2020; Rao and Wani, 2011).

AquaCrop yield response model has been applied to a wide range of crops, including maize (Muigai et al., 2021) and Onions (Karuku and Mbindah, 2020). Heng et al. (2009) and Hsiao et al. (2009) found out non-limiting conditions when modelling maize growth and grain yield, including water variables such as WUE and ETc when using the AquaCrop model. Nonetheless, several research show that in extreme water stress conditions, model performance in estimating specific variables deteriorates (Toumi et al., 2016 and Katerji et al., 2013).

Although the application of conservative parameters employed in crop simulations is a highlight of the model, various researchers have noted that model parameterization is fundamentally site-specific (Hsiao et al., 2009). To improve the dependability of the simulated findings, those critical calibrated parameters required for accurate simulation must be validated under various climate, soil, cultivars, irrigation systems, and field management conditions(Faraahami et al., 2009, Garcia et al., 2009; De casa et al., 2013).

5.2 Materials and Methods

As outlined in chapter three sections 3.1 to 3.9.

5.3 Aqua Crop Model Description

AquaCrop, a water productivity model developed by FAO to simulate biomass accumulation in crop and crop yield under water limiting conditions (Raes et al., 2009; Steduto et al., 2009) was used in this study. AquaCrop has an advantage over other models as it requires less data input that is easy to obtain (Paulo et al., 2018). The structure of AquaCrop has six main components to calculate crop growth, which include; crop, atmosphere, soil, irrigationparametersand field management (Cong et al., 2016). AquaCrop model has two forms of files;input data, and output data files. Input files include climate, soil, crop, irrigation, and cultural practicesdata, while crop growth, biomass production, yield, soil water balance, water productivity, and irrigation requirements are output data. A climate file (file CLI) was created in the AquaCrop model for this study. This climate file contained rainfall

(PLU file), temperature (TMP file), ETo (ETo file), and CO_2 (CO_2 file) that were used to run the model.

The climate file created for the experimental period was used to calibrate the model.

In contrast, climate files created for baseline (1986-2005) and future climate (2020-2039) and (2040-2059) were also used for simulation for predicting the crop growth and yield in the baseline and next period. The crop file (CRO) was created based on the characteristics of Duma 43 maize variety. The soil file (SOL) was created based on the recommendation made after soil analysis. The initial soil moisture content was set at field capacity. Four irrigation (IRR) files were created based on the four DI treatments selected for this study; including 100% field capacity, 75% field capacity, 50% field capacity, and 25% field capacity. The control treatment was set at a rain-fed condition. 0% and 100% soil surface mulching with organic residues wasconsidered as an in-field management file (MAN) to evaluate the effect of mulching on maize yield.

5.3.1 Crop Canopy Cover Data

The relationship between leave area index (LAI) and canopy cover (CC) used for maize crop is presented in Equation 4, adapted from (Heng et al., 2009; and Hsiao et al., 2009) was used to obtain CC in this study. The maximum canopy cover (CCx) is adjusted by AquaCrop from plant density information as shown in Equ. 15.

$$CC = 1.005\,[1 - \exp(-0.6\,LAI)]^{1.2} \qquad 15.$$

5.3.2 Climate data

The climate file consists of rainfall (mm), temperature (OC), sunshine hours, relative humidity (%), wind speed (ms^{-1}), reference evapotranspiration (mm), and carbon dioxide concentration (CO_2) as shown in Table 9 and 10. The climate data were obtained from the Kenya meteorological station near the study site. Reference evapotranspiration (mm) was calculated based on the FAO Penman-Monteith equation. Effectiverainfall was computed using the Soil Conservation Service method of the United States Department of Agriculture (USDA) described by Allen et al. (1998). Monthly carbon dioxide (CO_2-2021) concentration data was obtained from Mauna Loa observatory in Hawaii and arrange in notepad and imported to AquaCrop to create a CO_2 file (Benedict et al., 2018).

The goal of this study was to investigate the impact of climate change on maize production in the Kiboko area under two scenarios: one in which CO_2 concentrations do not considerably increase beyond current atmospheric levels, and another in which CO_2 strength grows exponentially.RCP4.5 and RCP8.5 are the RCPs that are being examined for future climate projections.The RCP4.5 scenario corresponds to a future with some type of climate policy, with CO_2 concentrations stabilizing at 650 ppm equivalent after the year 2100, whereas RCP8.5 represents a 'business as usual' future scenario, with CO_2 concentrations greater than 1,370ppm equivalent and growing in 2100.Carbon dioxide concentration (CO_2) data are available in AquaCrop version 6.0.

Table 9: Mean monthly climate data during the baseline and predicted future periods generated by IPSL CM5A MR Global Circulation Model (GCM) for the study (2020 -2039)

	Baseline (1986-2005)				Future (2020-2039) RCP4.5				Future (2020-2039) RCP8.5			
Mon	Tmin (^{O}C)	Tmax (^{O}C)	Rain (mm)	ETo (mm)	Tmin (^{O}C)	Tmax (^{O}C)	Rain (mm)	ETo (mm)	Tmin (^{O}C)	Tmax (^{O}C)	Rain (mm)	ETo (mm)
Jan	17.8	31.4	38.0	5	19.6	31.1	53.4	4.7	20.2	31.7	43.0	4.7
Fed	18.5	32.6	28.3	5.4	20.2	32.1	45.5	5.0	20.3	32.7	49.3	5.0
Mar	19.3	32.4	64	5.2	20.5	32.8	51.9	5.1	21.0	33.3	49.9	5.2
Apr	19.5	30.9	134	4.6	21.1	32.5	56	4.7	21.7	32.4	83.3	4.6
May	18.8	29.6	96.9	4.1	20.7	30.2	80.1	3.9	21.0	30.1	83.7	3.8
Jun	17.7	28.9	43.5	3.9	19.8	29.8	29.5	3.8	20.1	29.9	40.5	3.8
Jul	17.1	28.2	35.3	3.9	19.2	29.4	28.6	3.9	19.6	29.8	32.9	3.9
Aug	17.3	28.6	37.1	4.2	19.3	29.7	72.7	4.1	19.5	29.9	32.2	4.2
Sep	17.5	30.1	30.9	4.7	19.8	29.7	50.1	4.2	20.2	29.9	58.1	4.3
Oct	18.4	30.9	62.6	4.9	20.4	30	84.7	4.3	20.7	29.5	118	4.1
Nov	18.6	30.3	102	4.6	20.4	28.8	147	3.8	20.7	29.5	133	4.0
Dec	18.1	30.6	60.5	4.7	19.8	29.5	91	4.1	20.3	29.9	99.7	4.0

Legend: Tmin – Minimum temperature, Tmax – maximum temperature, ETo – Reference evapotranspiration

Table 10: Mean monthly climate data during the baseline and predicted future periods generated by IPSL CM5A MR Global Circulation Model (GCM) for the study area (2040 - 2059)

	Baseline (1986-2005)				Future (2040-2059) RCP4.5				Future (2040-2059) RCP8.5			
Mon	Tmin (^{O}C)	Tmax (^{O}C)	Rain (mm)	ETo (mm)	Tmin (^{O}C)	Tmax (^{O}C)	Rain (mm)	ETo (mm)	Tmin (^{O}C)	Tmax (^{O}C)	Rain (mm)	ETo (mm)
Jan	17.8	31.4	38	5.0	19.1	30.5	54.9	4.6	19.2	31	52.9	4.7
Fed	18.5	32.6	28.3	5.4	19.3	31.9	31.3	5	19.5	31.9	36.8	5
Mar	19.3	32.4	64	5.2	19.9	32.4	50.3	5.1	20.1	32.5	53.2	5.1
Apr	19.5	30.9	134	4.6	20.6	31.3	80.3	4.5	20.1	31.7	68.2	4.6
May	18.8	29.6	96.7	4.1	20.1	29.9	64.3	3.9	20.3	29.9	76.5	3.9
Jun	17.7	28.8	43.5	3.9	19.3	29.2	31.1	3.7	19.3	28.9	40.9	3.7
Jul	17.1	28.2	53.3	3.9	18.7	29.1	25.7	3.9	18.8	29.3	21.9	3.9
Aug	17.3	28.6	37.1	4.2	18.7	29.2	34.6	4.1	18.9	29.3	35.9	4.1
Sep	17.5	30.1	30.9	4.7	19.4	29.2	59.6	4.2	19.5	29.2	66.3	4.1

Oct	18.4	30.9	62.6	4.9	19.9	28.7	139	4	20	29.1	120	4.1
Nov	18.6	30.3	102	4.6	19.7	28.3	144	3.8	19.8	28.5	143	3.9
Dec	18.1	30.6	60.5	4.7	19.2	29.5	75.9	4.2	19.5	29.7	85.9	4.2

Legend: Tmin – Minimum temperature, Tmax – maximum temperature, ETo – Reference evapotranspiration

Table 11: Preliminary input parameters of maize calibrated in AquaCrop model to simulate the growth and yield of maize in the study area

Parameter	**Model input**
Base temperature (^{O}C)	8
Cut-off temperature (^{O}C)	30
Crop Coefficient (Kcb,x)	1.05
Upper and lower thresholds of soil water depletion factor	0.2-0.8
Shape factor for water stress coefficient for canopy expansion	2.9
Soil water depletion fraction for stomatal control (p-sto)-upper threshold	0.45
Shape factor for water stress coefficient for stomatal control	0.2
Canopy growth coefficient (CGC)	15.2
Canopy decline coefficient (CDC)	10.4
Maximum canopy (CCx) infraction soil cover	0.92
Minimum effective rooting depth (m)	0.4
Maximum effective rooting depth (m)	1.2
Building up of harvest index starting at flowering (days)	50
Normalized water productivity (WP) (gm-2)	35.7
Harvest index (percentage)	48
Number of plants per hectare	55555

5.4 Model Validation and Evaluation

The accuracy of AquaCrop model simulated results to fit the observed yield, CC and biomass were evaluated using four statistical variables: The Root Mean Squared Error (RMSE)(Equ. 16), the model efficiency (E) (Equ. 17), Willmott's Index of Agreement (d) (Equ. 18) and the coefficient of determination (R^2) (Equ. 19).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=0}^{n}(Pi - Oi)^2} \qquad 16$$

Where;

O_i and P_i are the measured and predicated values, respectively; n is the number of observations; and M is the mean of the observed values.

The Root Mean Squared Error (RMSE) is defined as the measure of the mean deviation between observed and predicted values. According to Moriasi et al. (2007), it indicates all the weaknesses of statistical indicators. The unit of RMSE is expressed in relation to the variable under investigation. RMSE values that are close to 0 indicate better agreement between observed and simulation values.

The *E* is the measure of the mean square to predicted variance. It indicates the deviation between observed and predicted values in relation to overall deviation between predicted values (O_i) and their mean values (O). According to Heng et al. (2009),*E* indicates the performance of the model over the whole simulation span compared to RMSE.

$$E = 1 - \frac{\sum_{i=0}^{n}(Oi - Pi)2}{\sum_{i=0}^{n}(Oi - \bar{O}i)2} \qquad 17$$

The index of agreement, *d*, is an indication of relative error in model predication. Zeleke et al. (2011) found out that an index of *E* indicates the predication performance while index of *d* measures the degree at which predicted and observed values similarities in their deviation from the observed mean. Index values ranges from 0 and 1 where perfect agreement between predicated and observed data are obtained when index is 1 and 0 indicates no agreement

$$d = 1 - \frac{\sum_{i=0}^{n}(Oi - Pi)2}{\sum_{i=1}^{n}(|Oi - \bar{O}i| + |Pi - \bar{O}|)2} \qquad 18$$

$$r^2 = \left(\frac{\sum_{i=1}^{n}(Oi - \bar{O})(P - P)}{\sqrt{\sum_{i=1}^{n}(Oi - \bar{O}i)^2}\sqrt{\sum_{i-1}^{n}(P - P)^2}}\right)^2 \qquad 19$$

Where

O_i = observed values, P_i = the predicted values, $\bar{O}$ =mean of the observed values, $\bar{P}$=mean of the predicted values and n = number of the observations.

Coefficient of determination values ranges between 0 and 1. Good agreement is obtained with values close to 1 and watershed simulation is considered acceptable with typical values > 0.5.

5.5 Results and discussion

5.5.1 Soil Characterization of the Study Site

The soil characterizations of study site are shown in Table 12. The particle size distribution shows that sand content was dominant.

Table 12: Salient physical soil properties of the experimental site for AquaCrop calibration

Soil	Texture	Bulk	FC	PWP(Vol.	AWC	Ksat

depth (cm)	%Sand	%Clay	%Silt	Class	density (g/cc)	(Vol. %)	%)	(V0l. %)	(mmday^{-1})
0 – 15	70	24	2	SCL	1.30	22.13	10.54	11.59	71
15 – 30	70	24	2	SCL	1.35	22.85	11.12	11.73	63
30 – 45	68	28	4	SCL	1.41	23.01	11.22	11.79	68
45 – 60	68	28	4	SCL	1.42	23.42	11.41	12.01	62
60 – 75	68	28	4	SCL	1.43	23.51	10.86	12.65	58
75 – 90	67	28	8	SCL	1.43	23.62	11.24	12.38	63
90 – 105	66	28	8	SCL	1.55	22.73	11.42	11.31	60
Average	68	27	5	SCL	1.4	23.01	11.1	11.92	63.5

Legend: SCL – Sandy Clay Loam FC – Field Capacity, PWP – Permanent wilting Point, AWC – Available water content, Ksat – Saturated hydraulic conductivity.

The soil content comprised of sand, 68, clay 27 and the silt content 5% thus the textural class of the soil was sandy clay loam according to the textural triangle. The bulk density indicated a slight variation with depth and ranged from 1.30 gcm^{-3} at the depth of 0 – 15 cm to 1.55 gcm^{-3} in the 90 – 105 cm depth. This could be because of decrease in organic matter content with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The soil moisture content at FC and PWP was at pF 4.2 and pF 2.0, respectively and the hydraulic conductivity; Ksatat 64 mmday^{-1} was deemed high which indicated high permeability of the soil.

5.5.2 Validation of simulated Yield and aboveground biomass usingAqua Crop model

Seasonal evolutions of observed and simulated maize yield in two seasons are tabulated in the Table 13.Generally, there is good agreement between observed and simulated yield in the two seasons as the RMSE was close to zero, and *d* and *E* were high tending toward unity, which indicates high model performance. The RMSE of T4 in season II is about 0.5 meaning the model slightly underestimated the yield as the crop was stressed by a 75% water deficit (25% field capacity).

Table 13: Validation results of simulated maize yield in five treatments

	Season I					Season II				
Treatments	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
R^2	0.99	0.99	0.98	0.99	0.98	0.99	0.9	0.99	0.98	0.98
RMSE	0.21	0.12	0.27	0.28	0.31	0.25	0.37	0.18	0.57	0.37
d	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
E	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.95

The findings were in line with those of Hsiao et al. (2009), for both seasons as the model simulated higher yield compared to the measured values. The slight overestimation in the initial growth stages of maize could result from some conservative parameters of AquaCrop that were not adjusted downward and upward. The comparison between average mean observed CC and predicted CC by AcquaCrop model plotted against days to physiological maturity are shown in Figure 5 and 6.

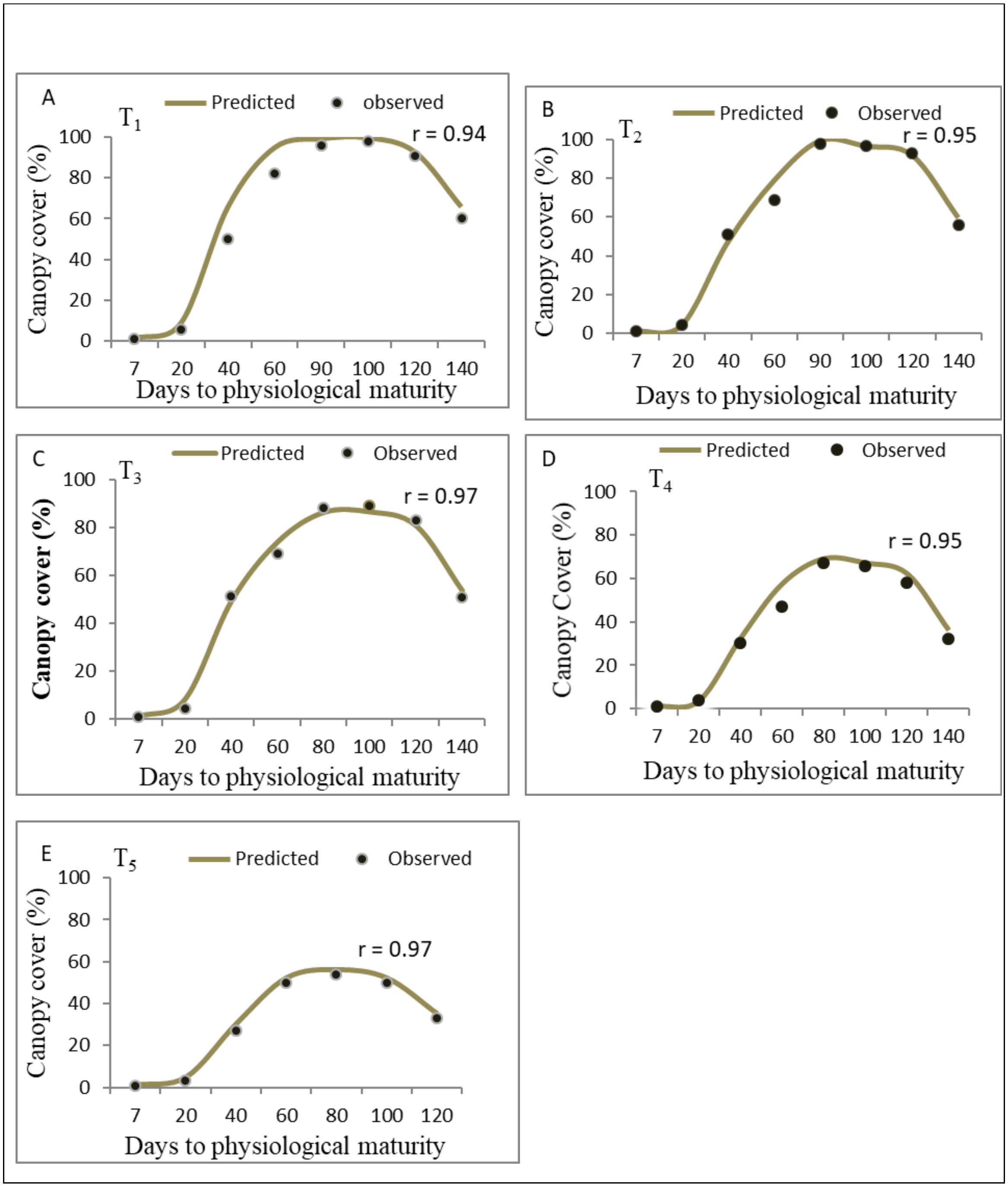

Figure 5: Predicted versus observed maize mean canopy cover in season I

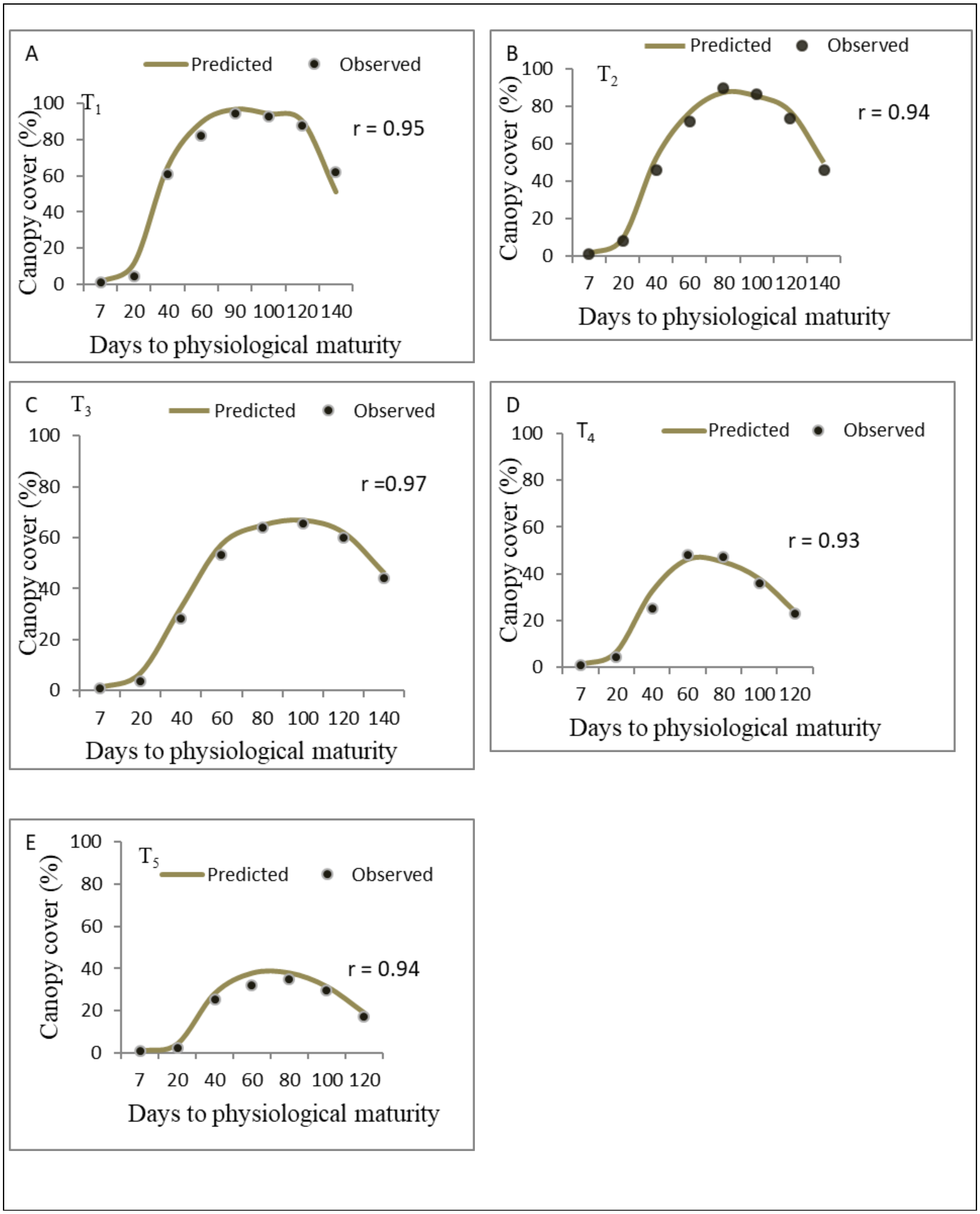

Figure 6: Predicted versus observed mean canopy cover in season II

The model has predicted the canopy cover with an average Pearson correlation coefficient (r) of 0.95 in all the treatments. The predictions were statistically satisfactory since the r– values were close to 1, an indication of a linear relationship between the observed and predicated values.

Values equal or close to +1 show a positive model precision. In general,prediction of the seasonal trend in CC was satisfactory. The predictions of slow crop establishment were observed in T4 and T5 with maximum CC of 40 and 50%, respectively, the slow growth could due high level of stress exposure of 25% field capacity (T4) and under rain-fed. The results were in agreement with Katerji et al. (2013) predictions of underestimated maize canopy and biomass in treatment with a server water stress while (Jin et al., 2014) obtained similar result for winter wheat where is this underestimation in your data.

5.5.3 Predicted aspects of rainfall

The predicted mean rainfall for the long rainy season (March - May) for future climate (2020 – 2039) will reduce from 134mm in the baseline period to 64mm in the RCP4.5 scenarios and will slightly increase to 97mm under RCP8.5 (Figure 7).

In the short rainy season (September – December) predicted rainfall will increase from 102mm in baseline to 148mm in RCP4.5 and reduce by 10.1% (15mm) in RCP8.5.

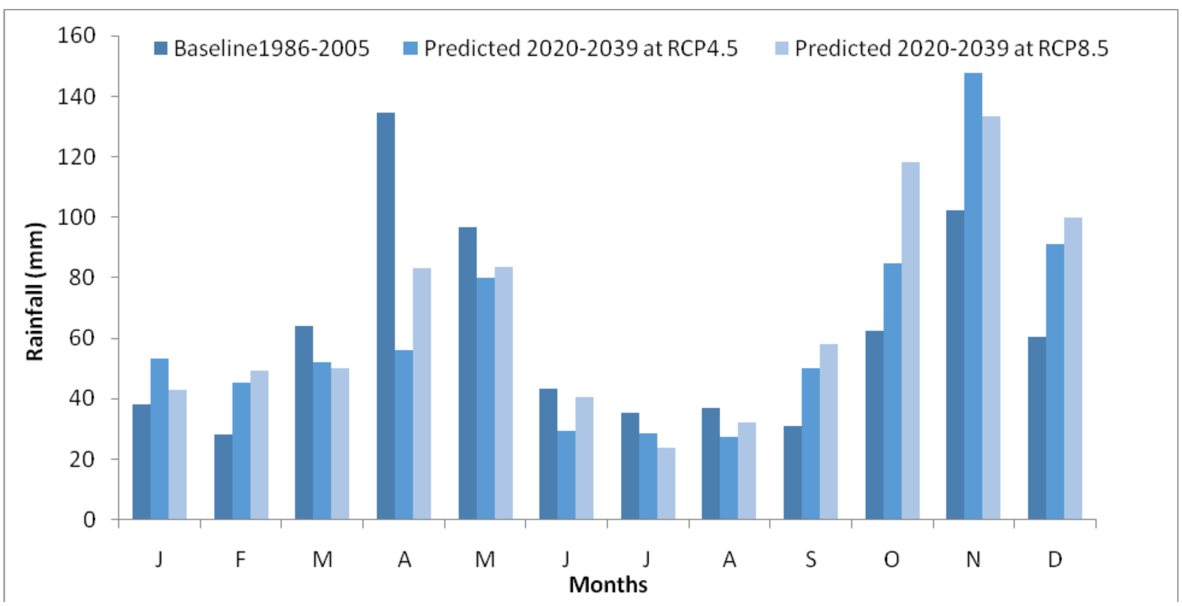

Figure 7: Mean monthly rainfall for baseline (1986 - 2005) predicted future (2020 - 39) at RCP4.5 and 8.5

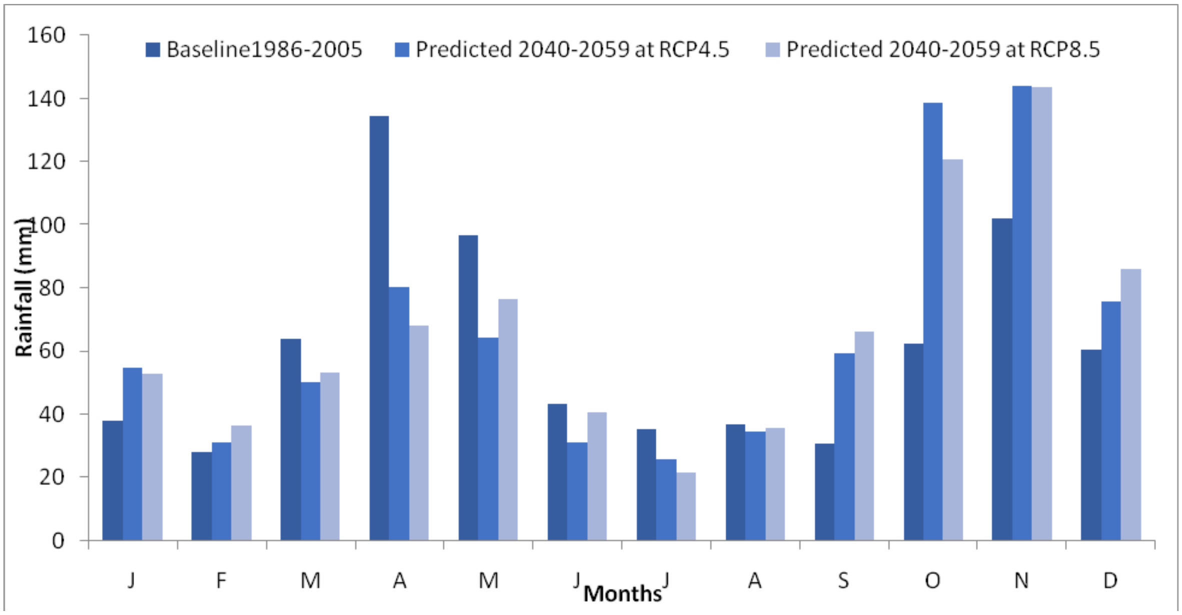

Figure 8: Mean monthly rainfall for baseline (1986 - 2005) predicted future (2040 -49) at RCP4.5 and 8.5

While in future climate 2040-2059, the mean monthly rainfall would reduce from 134 mm in the baseline to 80 mm in RCP4.5 and 76mm in RCP8.5 for the long rainy season whereas in the short rainy season, the mean monthly rainfall would increase from 102 mm in baseline to 144 mm in both climate scenario RCP4.5 and RCP8.5 respectively (Figure 8). The increase in rainfall could be as result of rising temperature in cold season.

Downing et al., (2008) found out seasonal variation in rainfall, which showed trend of extremely wet short rains in Kenya; therefore, farmers should adjust their planting date with the changing rainfall pattern to taken advantage of the excess rains to increase production. On other hand there is need to adopt more soil and moisture conservation techniques such as mulching and irrigation in dry months of the year to counter react the impact of climate change to ensure year-round production of crop.

5.5.4 Predicated aspects of temperature

There would be a rise in temperature from 26.9 ^{0}C in the baseline to 27.1^{o}C in projected future climate (2020 – 2039) under RCP4.5 and RCP8.5 respectively during the long rain season (Figure 9).

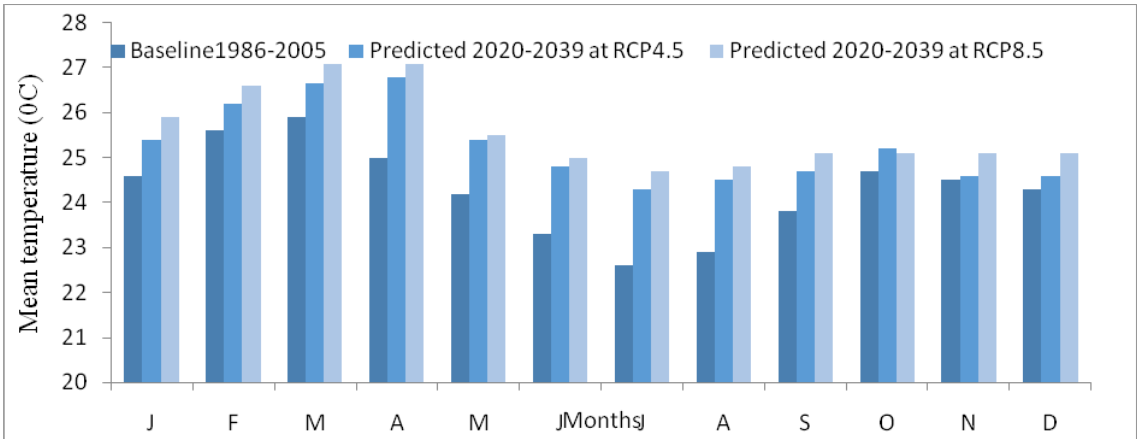

Figure 9: Mean monthly temperature for baseline (1986 - 2005) predicted future (2020 - 39) at RCP4.5 and 8.5

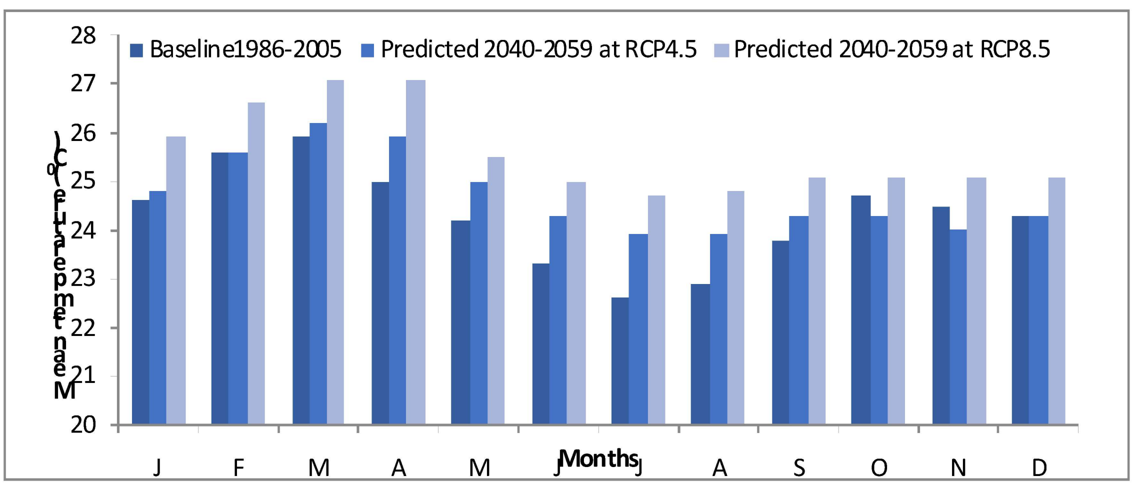

Figure 10: Mean monthly temperature for baseline (1986 - 2005) predicted future (2040 - 59) at RCP4.5 and 8.5

The hot months will change from February and March in baseline to March and April in RCP4.5 and RCP8.5 for 2020-2039 and 2040 -2059 (Figure 10). The cold season (June, July, and August) will experience raise in temperature from 22.6^{0C} in baseline to 25^{0C} in RCP4.5 and RCP8.5.

Therefore, the cold season will gradually become warmer as the temperaturecontinues to change with 1^{0}C in both RCP4.5 and RCP8.5 climate scenarios. The rapid increase in temperature during the cold season will have an impact on the growing degree days. There would be a slightly increase in temperature with 0.5 ^{0}C in predicted future climate (2020-2039 and 2040-2059) for both scenarios RCP4.5 and RCP8.5 during the short rainy season.

Plenty of scientific shreds of evidence confirm that climate change is already happening. One such observation is the global warming that has occurred over the last 100 years (IPCC 2007), with the global average surface temperature increasing by 0.74 0C. (1906-2005).
As a result, the effects of climate change on water resources systems must be appropriately addressed in order to ensure long-term water management.

5.5.5 Effect of climate scenarios on predicted maize yield under different water regimes

Predicted future climate 2020 - 2039 will record yields between 1.8t to 3.8tha^{-1}in the rain-fed condition, 11.7to 11.9tha^{-1} when full irrigation (T1 100% field capacity) is applied and 9.5tha^{-1} to 11.4tha^{-1} when 50% water deficit (T3 50% field capacity) under climate scenarios RCP4.5 and RCP8.5 in both season I and Season II, respectively (Table 14). The future climate 2040 - 2059 under RCP4.5 and RCP8.5climate scenarioswill record slightly high yields, with an average yield of 12.25 to 12.40tha^{-1} in T1 and 11.49 to 11.52tha^{-1} in T3 and rain-fed condition will record 1.4 to 6.9tha^{-1} compared to the baseline yields of 12.01 in T1 and 0.64tha^{-1} under rain-fed in season I and season II respectively.

Table 14: Effect of climate scenarios on predicted maize yield under different water regimes (tha^{-1})

Cropping Seasons	T	Climate Scenarios: Baseline (1986-2005)	RCP4.5 (2020-2039)	RCP4.5 (2040-2059)	RCP8.5 (2020-2039)	RCP8.5 (2040-2059)
Season I	T1	11.9a	11.7a	12.0a	12.1a	12.3a
	T2	11.7b	10.8b	11.6b	11.9b	11.9b
	T3	11.4c	9.5c	10.6c	11.7c	11.5c
	T4	9.4d	7.6d	5.7d	8.9d	8.5d
	T5	3.8e	1.8e	1.0e	3.2e	1.9e
Season II	T1	12.0a	12.5a	11.9a	12.1a	12.3a
	T2	9.0b	11.6b	11.5b	11.6b	11.8b
	T3	7.2c	11.1c	9.9c	9.8c	10.3c
	T4	3.9d	9.1d	7.5d	6.9d	7.4d
	T5	0.64e	4.9e	1.5e	1.4e	1.8e

Legend T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rainfed. Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

5.5.6 Effect of climate scenarios on predicted water use efficiency under different regimes of deficit irrigation

The predicted future WUE will have significant (P≤0.05) differences in relation to DI regimes (Table 15). In season I, WUEwill significantly (P≤0.05) increase from 18.1, 17.8 and 16.3 kgha^{-1}mm^{1} obtained from T2, T3 and T1 in the baseline to 27.4, 25.8 and 25.2kgha^{-1}mm^{-}

[1] in both predicted future climate 2020 -2039 and 2040-2059 under RCP4.5 and RCP8.5, respectively

Table 15: Effect of climate scenarios on predicted water use efficiency (kgha^{-1}mm^{-1})

Cropping Seasons	T	Climate Scenarios				
		Baseline	RCP4.5		RCP8.5	
		(1985-2005)	(2020-2039)	(2040-2059)	(2020-2039)	(2040-2059)
Season I	T2	18.1a	27.4a	25.9a	25.8a	27.5a
	T3	17.8a	27.0b	25.8b	25.1b	26.5b
	T1	16.3a	26.7c	24.8c	24.2c	25.9c
	T4	13.9a	25.0d	21.8d	19.9d	21.4d
	T5	10.2a	16.5e	5.1e	3.6e	6.2e
Season II	T2	26.5a	25.4a	28.1a	28.3a	29.2a
	T1	26.3b	25.0b	27.9b	28.2a	28.9b
	T3	25.5c	23.9c	26.9c	26.9b	27.9c
	T4	24.4d	22.2d	17.1d	24.8c	24.3d
	T5	12.0e	7.4e	4.01e	11.0d	6.9e

Legend T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

The long rainy season will tend to have an increase in WUE when the crop is under deficit irrigation (T2, T3) from 26.5kgha^{-1}mm^{-1} obtained in the baseline to 28.1 and 29.3kgha^{-1}mm^{-1} in RCP4.5 and RCP8, respectively.

The low WUE recorded in baseline period could be as a result of more reliable and sufficient rainfall, accompanied by low temperature that permit low transpiration rate while the high WUEthat will be recorded in future climate could be due to raise in temperature that promote high evapotranspiration and high grains yield. Loomis (1984), found a straight-line relationship between grain yield produced and the amount of water transpired, and the slope of the linedepends on the transpiration environment (Sinclair and Weiss 2010), and the findings showed a similar trend with high grains yield of 11.9 and 11.7tha^{-1} obtained in T2 and T3, respectively (Table 14).

5.5.7 Effect of climate scenarios on predicted net irrigation requirement of maize under different water regimes

Generally, deficit irrigation will have significant(P≤0.05) effect on predicted net irrigation requirement (NIR) and it varies according to the season and climate scenarios RCP4.5 and RCP8.5 (Table 16).

In season I NIR of 212.7mm was recorded in the baseline climate under full irrigation, and this will significantly ($P \leq 0.05$) increase to 243.7 mm in future climate 2020 – 2039 (RCP4.5) and will slightly decreased to 212.1 mm under RCP8.5 scenarios.Under50% water deficitsNIR will record 111.3 mm in baseline periodand will significantly ($P \leq 0.05$) increase to 189.3 mm and 152.3 mm under RCP4.5 and RCP8.5, respectively.

Table 16: Effect of climate scenarios on predicted net irrigation requirement of maize under different water regimes (mm)

Cropping Season	T	Climate Scenarios				
		Baseline	RCP4.5		RCP8.5	
		(1985-2005)	(2020-2039)	(2040-2059)	(2020-2039)	(2040-2059)
Season I	T1	212.7a	243.7a	207.1a	212.1a	204.1a
	T2	136.0ab	189.3b	186b	162.5b	159.4b
	T3	111.3abc	152.3c	158c	154.3c	146.2c
	T4	76.7bc	93.7d	85d	82.1d	86.3d
	T5	0.0c	0.0e	0.ee	0.0e	0.0e
Season II	T1	332.0a	280.1a	222.2a	260.1a	222.0a
	T2	228.3b	204.0b	174.4b	189.3b	174.3b
	T3	156.1c	142.2c	126.3c	152.3c	125.7c
	T4	82.7d	75.3d	65.3d	71d	67.2d
	T5	0.0e	0.0e	0.0e	0.0e	0.0e

Legend T1 (100 % field capacity), T2 (75 % field capacity, T3 (50% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at ($P \leq 0.05$) level.

In predicated future climate scenarios 2040 -2059, NIR will significantly ($P \leq 0.05$) increase from 212.7mm as recorded in baseline climate to 243.7mm under RCP 4.5 and this will reduce to 204.1mm in RCP8.5, seasonI. The variation in NIR in season I could be as result of seasonal variability of rainfall and increase in carbondioxide (CO_2) level in atmosphere which results to rise in temperature. The inverse association between seasonal rainfall and NIR has been discovered, with a drop in seasonal rainfall leading to an increase in NIR (Fares et al., 2016; Karuku et al., 2014a).In season II predicted future NIR was significantly ($P \leq 0.05$) increased by 12% and 18% in future climate 2020 – 2039 and 7.2% and 8.1% in 2040 – 2059 future climate under RCP4.5 and RCP8.5 respectively compared to season I. Generally high predicted NIR of 280.1mm was recorded in T1 followed by T2, T3 and the least will be obtained in T4 (25% field capacity) for both climatic scenarios and seasons.

5.5.8 Effect of mulching and no mulch on predicted maize yield under different deficit irrigation regimes

Generally mulching at 100% soil surface cover has significant (P≤ 0.05) increase in maize yield (tha^{-1}) (Table 17)

Table 17: Effect of mulching on predicted maize yield (tha^{-1}) (2020 - 2039)

		Climate Scenarios (2020 – 2039)					
		Baseline		RCP4.5		RCP8.5	
Cropping season	T	0% mulch	100% mulch	0% mulch	100% mulch	0% mulch	100% mulch
Season I	T1	11.9a	12.2a	11.9a	12.2a	12.1a	12.4a
	T2	11.7b	12.0a	10.8b	11.6b	11.9b	12.3a
	T3	11.4c	11.6b	9.5c	11.7c	10.7c	11.3b
	T4	9.4d	9.9c	7.6d	9.9d	7.6d	8.2c
	T5	3.8e	4.8d	1.6e	2.8e	2.2e	3.2d
Season II	T1	12.0a	13.2a	12.1a	12.5a	12.1a	13.6a
	T2	9.0b	11.8b	11.4b	11.6a	11.6b	12.1b
	T3	7.2c	8.6c	10.1c	11.5a	9.8c	11.9bc
	T4	3.9d	4.6d	8.5d	9.1b	6.9d	9.3c
	T5	0.64e	0.8e	4.5e	5.9c	1.4e	3.4d

Legend:0% mulch - no surface mulch, 100% mulch – entire soil surface covered by a mulch of organic material T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

The results indicated that mulching will significantly (P≤ 0.05) increase the predicted maize yield compared to no-mulch by 2.5% in both seasons under full irrigation. A significant (P≤ 0.05) increase in yield by 23% will be recorded in T4 under RCP4.5 and RCP8.5, respectively in future climate 2020 - 2039.

Under the rain-fed condition, mulching will significantly (P≤ 0.05) increase the maize yield by 30% in both seasons and climate scenarios. The prediction agrees with (Liu et al., 2013) that mulching can diminish soil temperature and hold way better root development in maize in coarse finished soil and improve grain yield. Haque et al. (2018) found out that mulching films can increase crop growth and yield.

Mulching acts as a barrier to prevent soil water evaporation and maintaining the moisture content to a reasonable level in the root zone(Li et al. 2011; Monneveux et al. 2006; Huang et al. 2008). Stabilization of soil moisture is important for the growth of crops, especially during the flowering stage when water deficits can directly affect crop yield(Chai et al. 2014). Soil water conservation effectively reduces the loss of agricultural production caused by erratic precipitation. Therefore 100% mulching has a vital role in effectively conserving rainwater in the soil, which can make more effective use of rainfall, increase the depth of infiltration and improve the utilization efficiency of rainfall (Dong et al., 2018; Gu et al., 2018; and Jiang & Li, 2015).

Table 18shows the effect of mulching and mulch on predicted maize yield under future climate 2040-2059.

Table 18: Effect of mulching and no mulch on predicted maize yield (tha^{-1})

		Climate Scenarios (2040 – 2059)					
		Baseline		RCP4.5		RCP8.5	
Cropping season	T	0% mulch	100% mulch	0% mulch	100% mulch	0% mulch	100% mulch
Season I	T1	11.9a	12.2a	12.1a	12.2a	12.3a	12.4a
	T2	11.7b	12.0a	11.6b	11.8b	11.9b	12.1a
	T3	11.4c	11.6b	10.2c	11.3c	10.5c	11.6b
	T4	9.4d	9.9c	5.7d	6.6d	8.5d	8.1c
	T5	3.8e	4.8d	1.0e	2.1e	1.9e	2.6d
Season II	T1	12.0a	13.2a	11.9a	12.3a	12.3a	12.4a
	T2	9.0b	11.8b	11.5b	11.7b	11.8b	12.3a
	T3	7.2c	8.6c	9.9c	11.1bc	10.3c	11.9b
	T4	3.9d	4.6d	7.5d	7.9c	7.4d	8.5c
	T5	0.64e	0.8e	1.5e	1.9d	1.8e	3.2d

Legend:0% mulch - no surface mulch, 100% mulch – entire soil surface covered by a mulch of organic material T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

In future climate (2040-2059), mulching will significantly (P≤ 0.05) increase maize yield by 10.8% both T3 and T5 under RCP4.5 and RCP8.5, respectively. Surface mulching has been shown to benefit crops in a variety of ways, including lowering runoff and water evaporation, controlling weeds, and adding organic matter to the soil, all of which improve soil quality (Kingra and Singh, 2016, Karuku et al., 2014a). Mulching improves crop growth and output while also conserving water (Yu et al., 2018).The findings are also consistent with those of (Pawar et al., 2003), (Yaghi et al., 2014), and (Ahmed et al., 2014), who found great efficiency in water and fertilizer usage, water patterns, and root distribution, all of which led to high maize yield. Similar studies have come to the same conclusion on the effect of mulching on water use efficiency (WUE) of crops (Mansouri et al., 2010; Jie et al., 2015; Ali et al., 2015; and Hou and Li, 2019). Mulching reduces soil evaporation and enhanced transpiration, which leads to increased yields and WUE of crops (Zhang et al., 2011).

5.5.9 Effect of mulching and no mulch on predicted WUE of maize under different deficit irrigation regimes

The predicted WUE significantly (P≤ 0.05) increased with the effect of 100% soil surface cover mulching in all treatment, seasons, and climate scenarios (Table 19).

Table 19: Effect of mulching on predicted maize water use efficiency (kgha^{-1}mm^{-1})

		Climate Scenarios (2020 -20-39)					
		Baseline		RCP4.5		RCP8.5	
Cropping season	T	0% mulch	100% mulch	0% mulch	100% mulch	0% mulch	100% mulch
Season I	T2	26.5a	29.6a	27.4a	30.4a	25.8a	30.3a
	T3	26.3b	29.5a	27b	30.3b	25.1b	29.0ab
	T1	25.5c	28.5b	26.7c	29.1c	24.2c	27.9b
	T4	24.4d	27.7b	25.0d	26.9d	19.9d	24.3c
	T5	12.0e	16.5c	16.5e	24.6e	3.6e	8.7d
Season II	T2	18.1a	18.1a	25.4a	28.3a	28.3a	30.9a
	T1	17.8a	17.8a	25.0b	27.9b	28.2a	30.9a
	T3	16.3a	16.3a	23.9c	27.9b	26.9b	30.3b
	T4	13.9a	13.9a	22.2d	25.9c	24.8c	27.9c
	T5	10.2a	10.2a	7.4e	19.6d	11.0d	12.8d

Legend:0% mulch - no surface mulch, 100% mulch – entire soil surface covered by a mulch of organic material T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

In future climate scenario 2020 – 2039under RCP4.5,WUE will significantly (P≤ 0.05) increase by 8.9 and 11.6% in both T1 and T2; 12.2 and 16.7% in T3, 7.6 and 16.6% in T4 and 69 and 137%will be recorded under rain-fed in season I and season II, respectively.

In RCP8.5, 100% soil surface mulching will lead to high significant (P≤ 0.05) increase in WUE in season I with 15 in T1, 17.4 in T2, 22 in T3 and 141% will be obtained in T5 compared to season II that will record 9.5 in T1, 9.7 in T2, 12 in T3 and 16.4% under rain-fed condition.

The variation could be attributed to the high rainfall predicted in season I-RCP4.5 and season II-RCP8.5 that indicate changes in climate in season I short rains (September to November) which provides realizable moisture under normal carbondioxide (CO_2) concentration while in season II, the long rains (March-May) is insufficient and unreliable. However, as CO_2 concentration increase in RCP8.5, the temperature raisesleading to high evapotranspiration, leading to high rainfall in season II.

Table 20 shows the effect of mulching and no mulch on predicted water use efficiency under future climate 2040-2059.

Table 20: Effect of mulching on predicted WUE (2040 - 2059)

		Climate Scenarios (2040 – 2059)					
		Baseline		RCP4.5		RCP8.5	
Cropping season	T	0% mulch	100% mulch	0% mulch	100% mulch	0% mulch	100% mulch
Season I	T2	26.5a	29.6a	25.9a	29.5a	27.5a	30.6a
	T3	26.3b	29.5a	25.8b	29.2a	26.5b	30.4a
	T1	25.5c	28.5b	24.8c	28.4b	25.9c	29.4b
	T4	24.4d	27.7b	21.8d	21.6c	21.4d	26.4c
	T5	12.0e	16.5c	5.1e	7.2c	6.2e	9.9d
Season II	T2	18.1a	18.1a	28.1a	30.8a	29.2a	32.2a
	T1	17.8a	17.8a	27.9b	30.5b	28.9b	32.1a
	T3	16.3a	16.3a	26.9c	30.5b	27.9c	31.6b
	T4	13.9a	13.9a	17.1d	25.6c	24.3d	27.8c
	T5	10.2a	10.2a	4.01e	7.9d	6.9e	12.2d

Legend: 0% mulch - no surface mulch, 100% mulch – entire soil surface covered by a mulch of organic material T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

RCP4.5, future climate 2040-2059 100% soil surface cover mulching will significantly (P≤0.05) increase WUE by 13% and 9.5% in full irrigation (T1), 14% and 9.6 in T2, 14% and 13% in T2, 49 and 17%, and 97 and 41% will be recorded under rain-fed condition in season I and season II respectively.

In RCP8.5 WUE will significantly increase by the effect of 100% soil surface cover in both seasons, 11 and 10% in T1, 11.3 and 11%in T2, 14.7 and 13% in T3 and 59.6% and 76.8% under rain-fed conditions in seasons I and season II, respectively. Zhang et al. (2017) studied the effects of mulch on WUE and found that it enhanced WUE by 61 percent due to a shift in the water balance and increased maize crop productivity.

5.5.10 Effect of mulching on predicted irrigation water requirement of maize under different deficit irrigation regimes

The effect of 100% soil surface cover mulching on net irrigation requirements will varyaccording to the amount of regulated deficit irrigation, season, and climate scenarios. The results (Table 21) show that 100% of soil surface mulching will havea significant (P≤0.05) effect on the net irrigation requirement (mm) of maize.

Table 21: Effect of mulching and no mulch on predicted net irrigation water requirement (mm) of maize under deficit irrigation regimes

		Climate Scenarios (2020 – 2039)					
		Baseline		RCP4.5		RCP8.5	
Cropping season	T	0% mulch	100% mulch	0% mulch	100% mulch	0% mulch	100% mulch
Season I	T1	212.7a	190.7a	213.7a	177.7a	212.1a	176a
	T2	136.0ab	125.5b	189.3b	167.7b	162.5b	144b
	T3	111.3abc	100.9c	152.3c	144c	154.3c	138c
	T4	76.7bc	67.2d	93.7d	79.7d	82.1d	72d
	T5	0.0c	0.0e	0.0e	0.0e	0.0e	0.0e
Season II	T1	332.0a	325a	280.1a	196a	260.1a	220a
	T2	228.3b	220.4b	204.0b	138b	189.3b	171b
	T3	156.1c	147.1c	142.2c	118c	152.3c	138c
	T4	82.7d	72.7d	75.3d	54d	71d	65d
	T5	0.0e	0.0e	0.0e	0.0e	0.0e	0.0e

Legend: 0% mulch - no surface mulch, 100% mulch – entire soil surface covered by a mulch of organic material T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at (P≤0.05) level.

In future climate scenario (2020 -2039), RCP4.5 indicate mulching will have significant (P≤0.05) reduction in net irrigation requirement by 16.8 and 30% in T1, 11.4 and 32% in T2, 14 and 28% in T3 while5.4 and 17% will be recorded in T4 compared to 6.2 and 2% obtained in T1, 8.4 and 3.5% in T2, 10 and 6% in T4 and 14 and 13% recorded in T4 in the baseline for both season I and season II, respectively.

The reduction in NIR could be as result of beneficial effect of mulching through preventing water loss by reducing soil evaporation. Mulch can enhance soil bio-engineers' activities such as earthworms, which helps in improving soil structure and nutrient cycling (Qin et al., 2015).Due to the interaction of the microclimate formed by mulch, soil environment, and plant growth (Steinmetz et al. 2016), the amount of water saved by mulching is still unknown.

In the climate future 2040 – 2049, net irrigation requirement will significantly (P≤0.05) decrease with the effect of 100% surface mulching (Table 16).

Table 22: Effect of mulching and no mulch on predicted irrigation water requirement (mm) of maize under different deficit irrigation regimes

		Climate Scenarios (2040 – 2059)					
		Baseline		RCP4.5		RCP8.5	
Cropping season	T	0% mulch	100% mulch	0% mulch	100% mulch	0% mulch	100% mulch
Season I	T1	212.7a	212.7a	207.1a	195a	204.1a	168a
	T2	136.0ab	136.0ab	186b	166b	159.4b	144b
	T3	111.3abc	111.3abc	158c	144c	146.2c	130c
	T4	76.7bc	76.7bc	85d	78d	86.3d	75d
	T5	0.0c	0.0c	0.ee	0.0e	0.0e	0.0e
Season II	T1	332.0a	332.0a	222.2a	192a	222.0a	189a
	T2	228.3b	228.3b	174.4b	165b	174.3b	163b
	T3	156.1c	156.1c	126.3c	116c	125.7c	115c
	T4	82.7d	82.7d	65.3d	59d	67.2d	60d
	T5	0.0e	0.0e	0.0e	0.0e	0.0e	0.0e

Legend:0% mulch - no surface mulch, 100% mulch – entire soil surface covered by a mulch of organic material T1 (100 % field capacity), T2 (75 % field capacity, T3 (5 0% field capacity), T4 (25 % field capacity) and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at ($P \leq 0.05$) level.

Under RCP4.5, NIR will significantly ($P \leq 0.05$) reduce with the effect of 100% surface mulching by 5.8% and 13.6% in T1 compared to 6.3 and 2% in the baseline, 8.8% and 8.2 when the soil moisture is maintained at 50% water deficit compared to 8.4 and 3.5% in the baseline in both season I and season II, respectively.

In RCP8.5, 100% soil surface cover mulching, NIR will have high significant ($P \leq 0.05$) decrease in both season I and season II by 17.7% and 14.9 when irrigating at 100% field capacity, 9.6% and 6.4 when 25% water deficit is applied, 11% and 8.5% when half irrigation is maintained throughout the growing season and 13% and 10 % decrease in net irrigation requirement when 75% water deficit was maintained.

The reduction in net irrigation requirement could be due improvement in water holding capacity of the soil. Swenson et al., (2004) and Headu and Kumar (2002) reported that mulching improves water infiltration and higher water retention capacity of the soil hence reducing the net irrigation requirement.

5.6 Conclusions

The impact of climate change on agricultural production in the study area under the two climate scenarios RCP4.5 and RCP8.5 respectively will have the following effects:

- The overall future temperature will increase by 1^0C, which will alter the rainfall pattern and net irrigation requirement for maize in the study area.
- Maize yield (tha^{-1}) will remain constant under irrigation management in the future though it will reduce or vary with the season under rain-fed conditions and amount of irrigation water applied.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 Discussion

Deficit irrigation is a technique for exposing a crop to drought stress by delaying irrigation at specified growth stages and/or reducing irrigation water application, either for a set period of time or throughout the growing season.As a result, crops under DI receive less water than they require for full irrigation, which enhances IWUE in exchange for a reasonable yield penalty under perfect conditions (Chai et al. 2016). When compared to the cost or value of water conserved in water-stressed areas, this yield penalty may be acceptable(Golizadi et al., 2017). Various crops have been successfully experimented and implemented under deficit irrigation water management system (Afshar et al., 2014). Deficit irrigation depends on number of factors such as the climate of the location, which dictates the evaporative demand on the crop and the soil type, which dictates the availability of water for plant uptake (Igbadun et al., 2008). Mulching is a water-saving strategy that conserves soil moisture, regulates temperature, and reduces evaporation in dry land areas (Yang et al. 2015; Kader et al. 2019a).

In rain-fed farming systems, surface mulching is commonly used as a water conservation measure(Chakraborty et al. 2008; Zribi et al. 2015). Mulching's main purpose is to reduce soil surface evaporation in order to maintain soil moisture, regulate soil temperature, and control soil erosion while also lowering irrigation water demand during crop growth stages (Qin et al. 2016; Kader et al. 2017b).

Several scholars have investigated the influence of climate change on maize output in Kenya. Mati 2002 and Karanja 2006 did a study on the impact of climate change on individual crops. However, their study is only focusing on rain-fed agriculture. This study has presented further knowledge on impact of climate change on irrigated agriculture and conservation practices that have be avail to reduce negative effect of climate change.

6.2 Conclusions

- Deficit irrigation at 75% field capacity (T2) and 50% field capacity (T3) will benefit practices as they improve water use efficiency with low net irrigation requirements and minimal yield losses in the study area.

- Deficit irrigation of 75% field capacity and 50% field capacity recorded the highest water use efficiency in the predicted future climate 2020-2039 and 2040-2059 under RCP4.5 and RCP8.5 climate change scenarios.
- Moisture conservation techniques that mitigate climate change, such as soil surface mulching, will improve soil water holding capacity and reduce soil surface evaporation and net irrigation requirements. Moisture conservation techniques will also reduce the effects of climate change.
- Net irrigation requirement for full and deficit irrigation in the predicted future climate scenarios varies with seasons and climate scenarios due to effect of climate change.
- The predicted maize yield by the AquaCrop model was accurately relevant compared to the observed yield, which shows indications that predicted future climate change would have a significant impact on the maize production in the study area.
- The predicated maize yield in the study area by the AquaCrop water productivity model was satisfactory and had a high accuracy level.

6.3 Recommendations

- Deficit irrigation should be practice in Kiboko area as it leads to achievement of high water use efficiency and water productivity, the productivity and stability of maize yield can be greatly increased through the addition of small amounts of deficit irrigation (50% field capacity) at the correct time, to reduce and eliminate the short-term risk of yield losses or crop failure under rain-fed condition.
- There is need for more extension services to farmers on benefits and importance deficit irrigation especially on the timings and amounts of DI scheduling.
- Deficit irrigation should be practices in combination with mulching to reduce the negative effect of climate change.
- Optimum and economic package/cost benefit analysis of deficit irrigation and mulching
- Comparative studies should be conducted on deficit irrigation with different moisture conservation techniques such mulching, cover crop and zip pit to determine a suitable adaptive measure that can be used to mitigate the predicted effect of climate change in the study area.

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APPENDICES

Appendix I: Tasseling and harvesting stage






Appendix II: ANOVA Table for effect on climate change on predicted maize yield (tha-1) in 2020-2039 under RCP 4.5 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	12.142	6.071	2.37	
Treatments	4	101.066	25.266	9.84	0.004
Residual	8	20.536	2.567		

Total	14	133.744

Appendix III: ANOVA Table for effect on climate change on predicted maize yield (tha-1) in 2020-2039 under RCP 4.5 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	32.1864	16.0932	73.36	
Treatments	4	188.1427	47.0357	214.4	<.001
Residual	8	1.755	0.2194		
Total	14	222.0842			

Appendix IV: ANOVA Table for effect on climate change on predicted maize yield (tha^{-1}) in 2020-2039 under RCP 8.5 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicates stratum	2	32.5532	16.2766	78.64	
Treatments	4	231.6585	57.9146	279.8	<.001
Residual	8	1.6559	0.207		
Total	14	265.8676			

AppendixV: ANOVA Table for effect on climate change on predicted maize yield (tha^{-1}) in 2020-2039 under RCP 8.5 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	33.4642	16.7321	20.91	
Treatments	4	173.6178	43.4044	54.25	<.001
Residual	8	6.4009	0.8001		
Total	14	213.4828			

Appendix VI: ANOVA Table for effect on climate change on predicted maize yield (tha^{-1}) in 2040-2059 under RCP 4.5 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	14.2172	7.1086	19.4	
Treatments	4	219.3957	54.8489	149.71	<.001
Residual	8	2.931	0.3664		

Total	14	236.5439			

Appendix VII: ANOVA Table for effect on climate change on predicted maize yield (tha^{-1}) in 2040-2059 under RCP 4.5 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	19.5524	9.7762	32.86	
Treatments	4	272.3309	68.0827	228.85	<.001
Residual	8	2.3799	0.2975		
Total	14	294.2633			

Appendix VIII: ANOVA Table for effect on climate change on predicted maize yield (tha^{-1}) in 2040-2059 under RCP 8.5 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	13.9629	6.9815	27.52	
Treatments	4	237.3961	59.349	233.96	<.001
Residual	8	2.0293	0.2537		
Total	14	253.3884			

Appendix IX: ANOVA Table for effect on climate change on predicted maize yield (tha^{-1}) in 2040-2059 under RCP 8.5 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicates stratum	2	14.7235	7.3617	36.42	
Treatments	4	227.7834	56.9458	281.75	<.001
Residual	8	1.6169	0.2021		
Total	14	244.1238			

AppendixX: ANOVA Table for effect on climate change on predicted water use efficiency of maize (Kg^{-1}mm^{-1}) under RCP 4.5 2020-2039 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	25.1404	12.5702	43.7	
Treatments	4	252.9828	63.2457	219.87	<.001
Residual	8	2.3012	0.2877		

Total	14	280.4244

Appendix XI: ANOVA Table for effect on climate change on predicted water use efficiency of maize ($Kg^{-1}mm^{-1}$) under RCP 4.5 2020-2039 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	25.4642	12.7321	43.03	
Treatments	4	696.4584	174.1146	588.43	<.001
Residual	8	2.3672	0.2959		
Total	14	724.2898			

Appendix XII: ANOVA Table for effect on climate change on predicted water use efficiency of maize ($Kg^{-1}mm^{-1}$) under RCP 8.5 2020-2039 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	25.4642	12.7321	43.03	
Treatments	4	696.4584	174.1146	588.43	<.001
Residual	8	2.3672	0.2959		
Total	14	724.2898			

Appendix XIII: ANOVA Table for effect on climate change on predicted water use efficiency of maize ($Kg^{-1}mm^{-1}$) under RCP 8.5 2020-2039 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	20.1767	10.0884	29.16	
Treatments	4	644.3356	161.0839	465.53	<.001
Residual	8	2.7682	0.346		
Total	14	667.2805			

Appendix XIV: ANOVA Table for effect on climate change on predicted water use efficiency of maize ($Kg^{-1}mm^{-1}$) under RCP 4.5 2040-2059 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	14.729	7.364	6.89	
Treatments	4	948.335	237.084	221.79	<.001
Residual	8	8.552	1.069		

Total	14	971.616			

Appendix XV: ANOVA Table for effect on climate change on predicted water use efficiency of maize ($Kg^{-1}mm^{-1}$) under RCP 4.5 2040-2059 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	25.7635	12.8818	45	
Treatments	4	1315.6346	328.9086	1148.95	<.001
Residual	8	2.2902	0.2863		
Total	14	1343.6883			

Appendix XVI: ANOVA Table for effect on climate change on predicted water use efficiency of maize ($Kg^{-1}mm^{-1}$) under RCP 8.5 2040-2059 season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	24.895	12.447	11.38	
Treatments	4	941.861	235.465	215.21	<.001
Residual	8	8.753	1.094		
Total	14	975.509			

Appendix XVII: ANOVA Table for effect on climate change on predicted water use efficiency of maize ($Kg^{-1}mm^{-1}$) under RCP 8.5 2040-2059 season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	33.7362	16.8681	21.07	
Treatments	4	1071.1982	267.7996	334.48	<.001
Residual	8	6.4052	0.8007		
Total	14	1111.3396			