PRODUCTIVITY AND PROFITABILITY OF SELECTED CABBAGE VARIETIES UNDER VARYING DRIP IRRIGATION SCHEDULES IN *HUMIC NITISOLS* OF EMBU COUNTY

STEPHEN ONYIEGO ONKOBA (BSc)

ATHESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL RESOURCE MANAGEMENT OF THE UNIVERSITY OF EMBU

AUGUST, 2022

DECLARATION

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

Signature: …………………………………… Date: ……………………

Stephen Onyiego Onkoba, BSc
A500/1213/2019
Department of Water and Agricultural Resource Management

This thesis has been submitted for examination with our approval as the University Supervisors

Signature: …………………………………… Date: ……………………

Dr. Charles N. Onyari, PhD
Department of Water and Agricultural Resource Management
University of Embu

Signature: …………………………………… Date: ……………………

Dr. Bernard M. Gichimu, PhD
Department of Water and Agricultural Resource Management
University of Embu

COPYRIGHT

©2022

DEDICATION

I dedicate this work to my lovely daughter Kayla Moraa.

ACKNOWLEDGEMENT

I would like to acknowledge the generous support I received at individual and institutional level towards making my research work and thesis a success. Above all, I would start by thanking the Almighty God for the gift of life, strength and health throughout my academic journey. Secondly, I also acknowledge the relentless efforts from my supervisors Dr. Charles N. Onyari and Dr. Bernard M. Gichimu in guiding me through the entire process; their patience reading every piece of my work from proposal development, manuscript and finally thesis writing. Their valued critique and input aimed at improving the quality of this work made it a success. The rapport and atmosphere they created during this journey, their availability every moment I needed them was a great motivation in fulfilling this research work. I also feel honored to have been awarded a scholarship by the University of Embu to pursue my Master of Science program at a very timely juncture. I feel indebted for this privilege considering the value it has contributed to my academic heights and realization of my desires. A conducive atmosphere created for postgraduate students in the varsity alongside several educative workshops by the Board of Postgraduate studies, vast learning resources and reliable E-learning platform provided a favorable atmosphere for my studies. I also wish to acknowledge a formidable team of friends and colleagues that surrounded me, day-by-day, encouraging me, giving me all the support I needed to move a step ahead. I found their passion in research and the desire to improve the quality of my work encouraging especially when I felt aloof facing the challenges that piled along the journey. I cannot afford to forget the efforts of the technical staff in the School of Agriculture for their unwavering help in ensuring I got all the kind of support I needed to accomplish this study. Am indebted to my mother Naomi and my brothers Kevin and Davis, my wife Phylice and my daughter Kayla for their moral support and allowing me to use the family resources during the entire period of this research. Their understanding of my situation and daily motivation to keep working hard was invaluable. My special thanks go to my mother Naomi and siblings Kevin and Davis for their wholehearted support and sacrifices they had to make just to see me through this academic journey. I am so grateful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zone
ANOVA	Analysis of Variance
ASAL	Arid and Semi-Arid Land
CROPWAT	Crop Water Model
CSA	Climate Smart Agriculture
ET	Crop Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FC	Field Capacity
MC	Moisture Content
NDMA	National Drought Management Authority
RCBD	Randomized Complete Block Design
SNK	Student Neuman's Keuls
SWC	Soil Water Content
WUE	Water Use Efficiency
WP	Water Productivity

DEFINITION OF TERMS

Crop water use efficiency is the ratio of the output of a crop to the volume of water applied, including the losses (Irmak *et al.*, 2011).

Agro-ecological zones (AEZs) are areas with similar sets of potentials and constraints that are defined by prevailing climatic conditions, soils, vegetation and physiographic factors (Chikodz *et al.*, 2013).

Green Water is that portion of precipitation water that remains within the crop rooting zone (Rost *et al.*, 2008).

Blue Water refers to all surface and ground water (Rost *et al.*, 2008).

Productivity is the ratio of the output realized to the unit input resources used in production (Plag, 2020).

Profitability refers to the ability of the business to make a profit usually expressed as a percentage ration of profit to the gross revenue realized (Hofstrand, 2009).

ABSTRACT

The adverse effects of climate change and increasing human population have put pressure on scarce water resources used in crop production. This consequently threatens the food and nutritional security of the growing human population. Vegetables are short season crops that are sensitive to water deficits during growth, leading to low productivity, poor marketability and reduced household incomes. Use of controlled irrigation in production of vegetables is considered a sustainable route for enhancing input use and productivity. This study sought to evaluate the effects of crop variety and drip irrigation schedules on productivity and profitability of cabbage grown in *humic nitisols* in Embu County, Kenya. The study applied a split plot laid in Randomized Complete Block Design (RCBD) in which the drip irrigation schedules were allocated the main plot and crop varieties were allocated the sub-plot treatments. The test varieties investigated were Riana F_1, Gloria F_1 and Triperio F_1. The four irrigation schedules were arranged as follows: application twice a week as S_1, application once a week as S_2, application once after every two weeks as S_3 and a control (no irrigation at all) as S_4. The treatments were replicated three times. Data was collected on the amount of irrigation water used, production cost, yield and income from the cabbages. The data were subjected to Analysis of Variance using SAS version 9.4. Mean separation was done using Fischer's least significant difference at *P=0.05*. An accounting profit approach was used to assess profitability from the selected irrigation schedules and varieties. The findings revealed that the yields of different cabbage varieties were not significantly different. Irrigation schedule 1 (S1) produced the highest average yield of 65.66 t ha^{-1} followed by S2 with 52.26 t ha^{-1}, S3 with 38.75 t ha^{-1} and S4 with 24.87 t ha^{-1}. Water use efficiency was significantly different across the four irrigation schedules. The control treatment plots recorded the highest water use efficiency at 70% in season one and 77% in the second season. Irrigation schedule 1 (S_1) recorded the lowest water use efficiency of 46% in season one and 49% in season two which indicates that water productivity and efficiency reduced as the amount of water applied increased. In terms of production cost, S_1 had the highest production cost ($2,103) but also gave the highest net revenue of $ 5,947 in season one and $ 4,460 in the second season. S_4 recorded the least production cost ($1854) and net revenue ($1,575 in season one and $2,011 in season two). There were no significant differences among the three cabbage cultivars assessed in terms of production cost and net revenue in the second season. However, in season one, the cost of production for Triperio F_1 variety ($2,019) was significantly different from that of Riana F_1 and Gloria F_1 cultivars ($1,959) while the latter two cultivars were not statistically different from each other. Net revenue for statistically different between Gloria F_1 ($3,853) and Triperio F_1 ($3,028) varieties but there were no significant differences between Gloria F_1 and Riana F_1 as well as Riana F_1 and Triperio F_1. These findings were significant for quantifying the impact of irrigation scheduling decisions with regard to water management in cabbage farming. The study therefore recommends adoption of irrigation schedule (S1) in order to optimize on cabbage yield reflected by the head weight and better stand count of the three cabbage varieties. There were no significant effects on the test cabbage varieties among the productivity parameters assessed under different irrigation schedules thus farmers may select any of the three cabbage varieties based on other production factors (agronomic variations, customer preference, and marketability).

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Over the recent decades, climate change has brought about sporadic weather patterns that have resulted to poor rainfall distribution. This has led to decline in availability of agricultural water, consequently reducing the potential for agriculture (Kang *et al*., 2009). Eastern region in Kenya, which includes Embu County, is battling with the impact of climate change. Food prices have skyrocketed thus contributing to food insecurity and malnutrition due to limited production and ability to access food (Cohen and Garrett 2010). Since agriculture in this region is basically rainfed, adoption of alternative strategies of farming such as irrigation would be a significant coping strategy to sporadic rainfall distribution (Kisaka *et al*., 2013). The County stands unique among other counties having all the five Agro-Ecological Zones (AEZ) present within its boundaries. The AEZs are useful in separating areas with similar sets of potentials and constraints for ease of development planning as defined by climatic conditions, soils, vegetation and physiographic factors (Muhajir *et al*., 2012).

Agriculture is the main economic activity in Embu County with approximately 70% of the residents being small-scale farmers (Korir *et al.*, 2015). However due to the challenges of water scarcity in the region, irrigation has been embraced to supplement erratic rainfall to sustain agricultural production. Growing of annual crops such as kales and cabbage *(Brassica oleracea* var. *capitata)* can be effectively achieved by appropriate irrigation technology especially where rainfed agriculture is not possible or where continuous supply of the produce is required (Ward, 2014). Though drip irrigation has been deemed efficient, scheduling of irrigation is still important in ensuring continuous productivity at a reduced cost among the small scale farmers (Ndhleve *et al.,* 2017).

Cabbage is a leafy biennial crop with dense-leaved head basically grown as a vegetable crop with red and white varieties being the common cultivars (Osondu *et al*., 2014). The crop is ranked as the 4th most popular vegetable in the world with an annual global production of 71.26 metric tons (Killebrew and Wolff, 2010). The crop originated from the Mediterranean region where it was first domesticated before 1000 BC. Currently, China, Russia and India are ranked as the world's leading producers of the crop (Ryder, 2011). In Africa, Kenya is among the few exporters of cabbages alongside other nations like Egypt, Angola, Rwanda and South Africa (Xie *et al*., 2014)

Cabbage thrives well under optimum conditions of well drained fertile sandy loam basic soils with a pH of 5.8 to 6.8, optimum temperature of 25 to 30 ºC for germination and 15 to 20 ºC for growth and head formation (Paranhos *et al*., 2016). The crop has abundant bioactive components that are essential elements for the human body (Caunii *et al.*, 2011). These components include antioxidants such as polyphenols that are key in inhibiting too much accumulation of free radicals in the body, and vitamin C (ascorbic acid) that boosts the body's immunity against scurvy and cardiovascular related ailments (McKeown *et al.,* 2010; Manchali *et al*., 2012). It is also rich in roughage that is essential in controlling constipation (Abdullahi and Abdulkareem, 2010) as well as glutamine and flavonoids that are excellent anti-inflammatory agents (Tang *et al.,* 2013).

Most studies in Kenya have focused on production of cereals and a few vegetable crops (Waddington *et al.,* 2010). Information on performance of most vegetable crops under irrigation among smallholder farmers is therefore scanty (Esteve *et al.,* 2014). Vegetables constitute the major portion of the daily human diet and their demand often surpasses the production capacity (Ndungu and Macharia, 2013). The low production of vegetables is attributed to several challenges facing agricultural production such as water scarcity, increased demand due to population increase, competing farm enterprises, and decline in soil fertility among other input resources (Muyanga and Jayne, 2014). Adoption of irrigation can therefore be used to ensure continuous production of vegetables and to reduce poverty levels among the smallholder farmers living in marginal areas with insufficient or poorly distributed rainfall (Pardossi and Incrocci, 2011). Provision of adequate information and irrigation infrastructure and their management is also key to improving the farmers' potential output and productivity (Fanadzo *et al.,* 2010a).

Tomato, cabbage, kales and Irish potatoes are the leading vegetables in Kenya produced due to their high demand with Central region being the leading producer of cabbage (Muriithi and Matz, 2015). Knoema (2021) statistics indicate that production of vegetables in Kenya has grown from 0.52% in 2015 to 26% (2.8 million tons to 3.6 million tons) between 2019 and 2020. Cabbage varieties grown in Kenya include golden acre, Copenhagen Market, Gloria F1, Queen F1 and Riana F_1. For instance, Gloria cabbage cultivar has a recommended spacing of 60 cm by 60 cm and can yield up to 27, 000 cabbage heads per hectare. Riana F1 cultivar is also another common cabbage preferred by farmers due to its great tolerance to heat and cold. This variety head can weigh between 1.5 to 2.5 kg per head and with an average stand count of 27000 per hectare, its yield is estimated between 45 to 90 tons per hectare. However, production has declined over the last ten years and this has been attributed to a number of production challenges. Sporadic weather patterns have been the key challenge that has made it hard to predict the onset and volume of rainfall expected especially on rainfed agriculture (Singh *et al.*, 2009). Other factors include declining soil fertility and scarcity of land due to the growing population (Kitalyi *et al.*, 2010). Despite vegetables being sensitive to water stress, cabbage production can be effectively achieved in dry seasons where irrigation is the main method of production (Jiang *et al.*, 2015). This study therefore evaluated the effect of drip irrigation and varietal factors on the performance of cabbage grown in Embu County.

1.2 Statement of the Problem

Agriculture in in the recent years has been constrained by inefficiency of resource utilization in attempt to achieve potential production as well ensuring sustainability of the resources. This (low production) condition has been worsened by the current irregular weather dynamics caused by climate change. Low and poorly distributed rainfall has resulted to degeneration of water resources, hence reducing the availability of agricultural water available for crop production, especially for vegetables where soil moisture requirement is high. This phenomenon poses a threat to the food security status in Kenya especially in arid and semi-arid parts of the country, including lower zones of Embu County. Majority of irrigation programs and studies have also given immense focus on production of cereal crops such as maize and rice while overlooking production of vegetables, despite their importance, potential productivity and profitability. Besides being essential source of food and nutritional security, vegetables are a viable economic opportunity that can be used to alleviate poverty and unemployment in the rural and developing economy like ours. A major challenge towards realization of this potential is limited information on efficient irrigation approaches and access to sufficient agricultural water for irrigation. This has subsequently increased the production cost and reduced the net profit margins on investment. Consequently, production trends are on the decline in contrast to the piling population whose growth rate has surpassed the food production potential of the agricultural fields. Therefore, food hunger index and malnutrition are expected to increase if agricultural productivity is not revitalized through sound management of declining water resources. For this reason, the current study was conducted to assess productivity of different varieties of cabbage and assess their profitability.

1.3 Justification of the Study

Vegetables are among the most suitable crops to grow during the dry seasons or in areas characterized by erratic and insufficient rainfall by use of supplemental irrigation. A study conducted by JICA describing the conditions suitable for vegetable farming match the prevailing agro-ecological characteristics in Embu County where the study was conducted. In addition, the high temperatures in these semi-arid areas significantly shorten the growing period of vegetables if adequate water is provided through appropriate method of irrigation. Therefore, water efficient irrigation methods need to be promoted in such areas to ensure sustainable agricultural productivity which would guarantee food security and wealth creation. The short growing season of cabbage and applicability of supplemental irrigation makes it profitable even with limited land.

Cabbage enjoys ready market in Kenya, being one of the most consumed vegetable that is rich in phytochemical components that are essential for the human body. This study used drip irrigation method due to its envisaged suitability and effectiveness in vegetable production and the economic benefits that come along due to its efficiency in resource use. The cabbage cultivars considered in this study were selected based on their preference among cabbage growers in Embu. The output would then inform possible recommendations for adoption by farmers and other related policy makers to promote performance and resource use efficiency of the small-scale farming activities involved in cabbage production. The information generated from this study is beneficial to the local vegetable growers in making appropriate choice of the cabbage cultivar based on their water requirements, especially during low rainfall production seasons. This study also provides an estimated returns on investment per unit area under production of cabbage which is a useful production guide for the local farmers.

Finally, the output of this study will contribute towards realization of the sustainable development goal number one and two that target to alleviate poverty and hunger respectively.

1.4 Objectives of the Study

1.4.1 General Objective

The broad objective of this study was to assess the productivity and profitability of cabbage varieties in response to varying drip irrigation schedules in *Humic Nitisols* of Embu County.

1.4.2 Specific Objectives

The specific objectives of the study were:

1) To determine the effect of different drip irrigation schedules on growth and yield of selected cabbage varieties.
2) To evaluate the effects of variety on growth and yield of cabbage.
3) To assess the water use efficiency of selected cabbage varieties under varying drip irrigation schedules.
4) To determine the profitability of different cabbage varieties under varying drip irrigation schedules.

1.5 Research Questions

1) What is the effect of varying drip irrigation schedules on growth and yield of cabbage?

2) What are the effects of variety on growth and yield of cabbage?
3) What are the effects of drip irrigation schedules on the water use efficiency of different varieties of cabbage?
4) How is the profitability of different cabbage varieties grown under different drip irrigation schedules?

CHAPTER TWO

LITERATURE REVIEW

2.1 Global State of Irrigated Agriculture

Agriculture accounts for about 70% of blue water withdrawals in the world and 90% of the green water consumption (Liu and Yang, 2010). In this case, green water is that portion of precipitation water that remains within the crop rooting zone while blue water accounts for all surface and ground water. It is approximated that about 270 million hectares (17%) of land worldwide is under irrigation and this portion contributes about 45% of the global food production (De Pascale *et al*., 2011). With the rising competition for the same resource with non-agricultural users and the ongoing effects of climate change, there is need to re-evaluate how better water use in crop production can be achieved through efficient irrigation methods. This will ensure sustainable management of the resource as one of the mitigation strategies of climate change.

Cropping intensity and improved yields can be achieved through integration of irrigation with the rainfed agriculture (Siebert *et al.*, 2010). Projections on the future demand for food is estimated to increase by 70% by 2050 (Wheeler *et al*., 2015). To achieve this, there is need for farmers to adjust their crop patterns, irrigation systems and technology that ensure efficiency of utilization of the resources so as to maximize investment returns. Irrigation efficiency is a term used to characterize irrigation performance, evaluate irrigation water use, and to promote better or improved use of water resources, particularly those used in agriculture (Pereira *et al.,* 2012). On the other hand, irrigation water productivity is the total yield per unit quantity of irrigation water used (Geerts & Raes, 2009).

A number of factors such as crop management, water management, soil preparation, climate, and soil type and crop variety have been reported to affect water productivity. Irrigation productivity (IP) is used to delineate the relationship between crop produced and the amount of water involved in crop production, (Ali & Talukder, 2008). Water use efficiency can be defined in terms of crop water use efficiency and field water use efficiency (Grewal *et al.,* 2011). Crop water use efficiency is the ratio of crop yield (kg/ha) to the amount of water depleted by the crop in the process of evapotranspiration (m3/ha) during the growing season (Sharma *et al.*, 2015). Crop water use efficiency is otherwise called consumptive water use efficiency. However, field water use efficiency is the ratio of crop yield to the total amount of water applied to the field during the growing season (Yi *et al.*, 2010).

Projections have shown that by 2030, the proportion of land under irrigation globally will rise by 27% while the expected water resources available will increase by 12% (Faurès *et al*., 2002). However, agricultural water use reports by Food and Agriculture Organization of the United Nations (FAO) have revealed that there is scanty information on agricultural water use in the developing world and this has made it difficult to estimate water balance for this region (Olmstead, 2010). A climatic risk analysis conducted by Agricultural Sector Development Support Program in Embu County revealed that all irrigation schemes in the County have embraced sprinkler irrigation (Miruri and Wanjohi, 2017). However, this method remains inefficient owing to the amount of water required for production (Heinke *et al.*, 2015).

Still, there is scanty information on vegetable production from these irrigation schemes. The study by Reed *et al.* (2015) considered only beans, maize and bananas in its productivity analysis. This indicates a knowledge gap on the performance of most horticultural crops including cabbages whose production can generate substantial revenue with minimal production investment.

2.2 Importance of Irrigation in Kenyan Agriculture

Currently in Kenya, there is 540,000 hectares that are irrigable but only 125,000 hectares have been equipped with irrigation (Water Fund Kenya). A breakdown of the irrigated land indicates that 40% is under private producers who do not necessarily engage in production of food crops, 42% is under smallholder farmers who produce vegetables for local market and 18% under the government control (Yu *et al*., 2014). This implies that smallholder farmers are the key producers and distributors of vegetables for the local market. A study by Xie *et al.* (2014) indicated that Kenya has abundant natural resources but still suffer from the threats of food insecurity. This implies that a bigger portion of agricultural land is left underutilized due to the lack of water.

According to the Embu County Climate Risk Profile assessment report, 20% of the households are still considered to be food insecure especially in the months of April to June. The challenges are engendered by factors such as adverse climatic conditions, extreme weather shocks, poor resource management, limited access to appropriate inputs, over-reliance on rainfed agriculture, poor irrigation governance, limited agricultural scientific input and high production costs among other factors (McCord *et al.,* 2015).

However, application of micro irrigation in vegetable production has proved to be suitable and effective in generation of household income, creation of employment and in ensuring food and nutritional security (Corbeels *et al.,* 2014). Xie *et al.* (2014) ascertained that supporting the arid and semi-arid parts of the country through investment in irrigation has a huge potential to yield lucrative returns on investment depending on the crop in question and the location's pricing trends. This study contributed towards provision of verified scientific input on the most productive cabbage variety as influenced by the most efficient drip irrigation schedule for local conditions.

Kand & Lutta (2022) provided the latest statistics indicating that 222,240 hectares were under developed irrigation scheme in Kenya. Comparing with the potential 1.3 million hectares that can be put under irrigation, this represents only 26% of the potential irrigable land mass thus showing need for more adoption of irrigation. The study further revealed that most of these schemes were using furrow system of irrigation with a few private farms using modern water efficient techniques. The challenges to slow adoption of efficient irrigation schemes included technical challenges (poor water infrastructure, water scarcity, and poor water quality), socio-economic challenge (high cost of irrigation systems, limited credit facilities, and lack of access to the market) as well as institutional challenges (existence of pluralistic legal frameworks, low farmer participation as well as improperly constituted irrigation water association). This study thus seeks to address the social economic and technical challenges by promoting adoption of drip irrigation method due to its water saving potential in order to sustain production amid water scarcity and recommendation of manual irrigation scheduling that is relatively cheaper that the automated system that are costly and sophisticated.

Facilitating cabbage production among smallholder farmers would create employment opportunities throughout the production chain and this could help increase the household income and the general welfare (De Zeeuw *et al.,* 2011). Kadiresan & Khanal (2018) argued that adoption of water management approaches such as irrigation can boost ecosystem services, water conservation, and water productivity and maintain agricultural water quality. Consequently, food production and productivity will be increased thus ensuring food security, flow of household livelihood and raw materials for agricultural value chains. Moreover, through well-managed irrigation approach, more land especially in water constrained areas can be opened up for agriculture which will then increase the production area, output and employment in agricultural value chain. A study by Broadbent *et al.* (2018) also indicated that irrigation induces a microclimate effects by cooling the air temperatures. Their study findings indicated that irrigation reduced the diurnal average air temperatures by up to 2.3 ^{0}C, increased humidity and improved outdoor human thermal comfort during heat wave conditions in Adelaide, Australia.

2.3 Vegetable Production in Kenya

The area set under vegetable production in Kenya has been gradually reducing over years as the available water for crop farming continues to decline (Muyanga and Jayne 2014). This has subsequently contributed to reduced production of vegetables despite their daily significance on human diet. A study by Lenné and Ward (2010) revealed that tomato, cabbage, kales, onions and indigenous vegetables are some of the common vegetables produced in Kenya. Their annual production is estimated to range between 250, 000 -350, 000 tons for tomatoes, cabbage and kales, 60,000 tons for onions and 70,000 tons for indigenous vegetables (Lenné and Ward, 2010). These results reveal that cabbage is among the leading vegetables sought among the vegetables consumed in Kenya. Cost of production per acre is estimated to cost up to $750 and the revenue from the investment is approximately $4500.

A human body requires about 300 g of vegetables a day for good health, which is approximately 109.5 kg per person per year (Muyanga and Jayne 2014). In relation to the current population in Kenya, the above production statistics are below the quantity required. In such a situation, forces of demand and supply could cause price shocks for the commodity and this can make cabbage production a lucrative business.

Stober *et al*. (2018) indicated that vegetable production that relies on rainfall has become unsustainable due to unpredictability of the rainfall in terms of distribution and quantities. The existing knowledge gap and the common tendency of farmers being risk averse in undertaking certain investments are still some of the major constraints among smallholder farmers to adoption of efficient and innovative techniques of production. (Rapsomanikis 2014). This implies that water efficient technologies such as drip irrigation are not yet adopted by most smallholder farmers. According to World Bank (2016), the horticultural sector in which vegetables such as cabbages are classified remains one of the backbone of the Kenyan economy (in terms of revenue) both in local markets and through exports.

Vegetable farming provides households with a source of livelihood throughout its chain of production to marketing. Promoting this sector is thus key to uplifting smallholder households from the below poverty line and also in contributing towards the realization of a semi-industrialized economy and a middle income classification as envisaged in the Kenya's Vision 2030 (Njenga 2015). Moreover, considering that only a third of the country's land is considered productive for farming, there is underutilized parcels of land that can be put into production through irrigation. With a mean annual precipitation estimated to be 680 mm (range between less than 250 mm in arid and semi-arid region to 2000 mm in high rainfall regions of western), this perhaps justifies United Nations' ranking of Kenya as a water scarce country.

Nonetheless, a report by the government of Kenya (2010) indicated that most horticultural operations in Kenya are done in arid to semi-arid lands compared to areas that receive high annual precipitation. This is because, horticultural crops are short seasoned thus easy to sustain in water constrained areas while crops such as cereals and cash crops are often produced in areas with high annual rainfall due to their high water requirements. A household survey conducted by Kebede, and Bokelmann (2017) between 2014 and 2016 revealed that 25% of farmers were irrigating their indigenous vegetables while 36% of those producing exotic vegetables such as cabbage and tomato were irrigating their crops.

2.4 Irrigated Farming, Water Productivity and Water Use Efficiency

Irrigation has been poised as the most efficient approach that should be adopted to overcome the challenges facing the rainfed agriculture (Olayide *et al*., 2016). The rationale for promoting irrigation water use efficiency in agriculture is to maximize crop growth and yield while conserving as more water as possible (Al-Said *et al*., 2012). Tilahun *et al.* (2011) conducted a comparative study to assess the performance of irrigated and rainfed agriculture in Ethiopia. The study revealed that irrigated agriculture performed better in terms of water use efficiency than rainfed agriculture especially in the face of soaring climatic stress productivity of rainfed agriculture (Singh *et al.,* 2020).

Irrigation scheduling is significant in establishing better agronomic practices with irrigated horticultural farming where the goal is to use resources optimally, reduce production costs and other on-site effects such as leaching, pests and weed infestations (Seidel *et al.,* 2017). It is a form of deficit irrigation used to determine the potential water use efficiency and productive levels that should be adopted when producing crops under water limited agricultural regions (Yanglem and Tumbare, 2014).

Agricultural productivity heavily relies on water availability (Fan *et al.,* 2014). As such, many studies have been dedicated to determine water use efficiency among different crops under various water management strategies (Njiraini and Guthiga, 2013). Nyambo and Wakindiki (2015) probed the crop water footprint for growing vegetables using the CROPWAT model. The study compared green beans and cabbage as the experimental crops. The results indicated that cabbage had the least water footprint as compared to the beans. The highest footprint reached for growing cabbage was 254.5 m^3 ton^{-1} compared to that of green beans' that stood at 3535.7 m^3 ton^{-1}. This implies that production of vegetables such as cabbage in regions experiencing water scarcity can be feasible and economical compared to certain crops like beans and the long-seasoned crops.

A study by Woltering *et al.* (2011) reported that irrigated vegetables (drip irrigated treatment) required a mean of 1.1 man hours per day to manage the garden vegetables while the treatment that simulated farmers practices needed 4.7 man hours a day to accomplish a similar task. This implies that shifting to drip irrigation could not only minimize utilization of water resources and maximization of revenue but also save on time that can be instead spent on other productive ventures. Though this study used eggplant as test crop, it corroborate on the objective of the current study that seeks to illustrate the positive impact of drip irrigation on potential profits at a minimum cost of resources such as water and crop management.

Irrigated farming practices provide a major source of livelihood (income and employment) among the majority of residents in the Sub-Saharan Africa. Because of limited land suitable for farming and high population, most of these farmers are smallholders and often use traditional practices to irrigate, manage their soil fertility as well as perform crop husbandry. Moreover, the methods of irrigation used are not resource efficient as they are labor intensive and often characterized with surface runoff due to the high irrigation intensity, deep percolation and evaporation. Since drip irrigation was introduced in 1960s, this method of irrigation has been reported to increase agricultural water productivity while improving both the physical and economic output with lesser water. The method directly delivers water to the root zone of the crop thus minimizing conveyance losses while promoting uniform distribution and at time specific intervals for the benefit of the crop. This structure/mode of delivery is also suitable to cut on cost of fertilizer application by mixing the irrigation water with soluble fertilizer, thus cutting on labor cost. Consequently, drip irrigation thus increases both yield and returns on investment while 50% of irrigation water compared to other irrigation techniques. Though the initial cost of purchase and installation is high, the saving made through use of the system are economically feasible to compensate for the initial costs.

An assessment by Mbava *et al.* (2020) on the factors affecting crop water use efficiency reported that rainfall pattern, soil type and climatic regimes are key factors that significantly affected crop water use efficiency. The study results indicated that cereals produced averagely 2.37 kg of dry grain per m^{-3} water applied. Other crops tested and their water use efficiency include the oilseeds (0.69 kg m^{-3}), fibre crops (0.45 kg m^{-3}) and legumes (0.42 kg m^{-3}). Another study by Al-Said *et al.* (2012) suggested that suitable combinations of vegetable crops that can be grown under drip irrigation to maximize profitability and optimize water productivity. The study findings revealed that cabbage and tomato performed better than roots and sweet pepper and melon in terms of water productivity with an average crop water productivity of 7.8 and 11.9 kgm^{-3} respectively. The results also indicated that drip irrigation method performed better than sprinkler irrigation. Compared to other available irrigation methods, drip irrigation method has been found to be more efficient in terms of water use (Dağdelen *et al*., 2009). Drip irrigation has also been found to be effective in reducing losses associated with overhead irrigation practices (Daccache *et al.*, 2015).

A meta-analysis on yields and water productivity of vegetables under deficit irrigation conducted by Singh *et al.* (2021) revealed that water productivity was significantly affected by deficit irrigation. Yield differences were also more prominent towards the lower irrigation regimes compared to the upper irrigation regimes. For instance, watermelon had a statistically similar yield under full irrigation and 80% full irrigation treatments. Pepper yield however declined gradually up to 50% water deficit then remained comparable with further irrigation reduction. Contrary to pepper, onions recorded a low to moderate decline in yield (8.2-25.6%) up to 50% water deficit then a drastic decline ensued with further reductions.

Another study by Roopashree *et al.* (2020) sought to evaluate water productivity, crop water use efficiency and irrigation water use efficiency of vegetable crops under temperate conditions using tomato, cucumber and bottle gourd as test vegetable crops. The subsequent mean yield for tomato, cucumber and bottle gourd under water stress conditions were 30.65 t ha^{-1}, 18.41 t ha-^{1} and 19.15 t ha^{-1}. Water productivity for tomato ranged between 5.3 – 13.45 kg ha^{-1} mm^{-1} while its water use efficiency ranged between 36.59 – 330 kg ha^{-1} mm^{-1}. The highest irrigation water use efficiency was 330 kg/ha/mm for tomato crops. Optimum results were obtained under the treatment where irrigation was provided at the initial and development stage while the rest of growth stages relied on rainfall. Similar trends for water productivity, crop water use and irrigation water use efficiency were observed with cucumber and gourd crop and the study concluded that field crops should be irrigated when the crop needs to enhance water productivity in order to save the limited water resources.

Albeit these findings indicate that productivity is largely affected by deficit irrigation, they did not consider cabbage as one of the vegetable crops and thus, literature on water use efficiency of cabbage remains scanty, which establishes the basis for the current study. Moreover, considering the new definitions of water productivity and water use efficiency, what has been termed as water use efficiency in previous studies prior to 2017 denote water productivity and not water use efficiency, hence there is limited literature on water use efficiency following the latest definition according to the FAO. The FAO (2017) defines water use efficiency as the ration between effective water use and the actual water withdrawal while water productivity is defined as the measure of economic or biophysical gain from the use of a unit of water consumed in crop production. The current study thus seeks to address this knowledge gap on water productivity and water use efficiency of selected cabbage cultivars by taking into account the latest models of determining WUE and WP.

Crop water productivity refers to the ratio of the crop output realized per unit (in cubic meter) of irrigation water used in crop production (FAO 2017). This water includes both green water (from rainfall) and blue water (from other sources diverted for irrigation purposes) (Rost *et al.,* 2008). Water productivity varies with different agro-ecological zones, type of crop and water management technology (rainfed or irrigated technology) (Aluku *et al.,* 2021).

2.5 Crop Water Requirement

Cop water requirement refers to the cumulative amount of water required for evapotranspiration, right from the planting stage till harvesting. Water requirements are specific to crops and specific climate regimes when sufficient soil water is sustained either by rainfall and/or irrigation in quantities that do not derail or limit the growth and yield potential of the crop (Adeniran *et al.,* 2010). Depending on the climate, stage of development of the crop and soil type, the frequency of irrigation varies from 3 to 12 days and a Cabbage water requirement throughout growing period ranges from 350 to 500 mm (Seidel *et al.,* 2017). Knowledge of crop-water requirements is crucial for water resources management and planning in order to improve water-use efficiency (Bastiaanssen *et al.,* 2005).

Past research has shown that cabbage varieties Gloria F_1 and Victoria F_1 produced the highest yield when planted during the long rains while Quick Start and Rotan varieties produced the best yield during the short rains (Šturm *et al.,* 2010). During the long rains, yields (in t ha^{-1}) for Gloria F_1, Pruktor F_1, Rotan, Victoria F_1 and Copenhagen Market were 44.0, 36.33, 26.33, 42.67 and 28.67 while the yield for short rains were 23.33, 22.33, 30.33, 32.86 and 31.67, respectively (Šturm *et al.*, 2010). Still the study revealed that Gloria F_1 matured early (85 days) with a good solid head than the other varieties. Therefore producing this vegetable crop during the dry season can be more profitable given that input resources such as water are properly managed and utilized efficiently.

2.6 Drip Irrigation and its Importance

Drip/trickle irrigation (also called micro-irrigation) is an irrigation method that allows application of irrigation water precisely to the irrigated crop in a controlled manner (Nakayama and Bucks, 2012). Drip irrigation technique allows water to flow through a filter into special drip pipes, with well-spaced emitters that discharge the water directly into the soil near the root zone of the crop. This technique is used to promote conservation of agricultural water by reducing evaporation and deep drainage (Fentahun, 2020). Drip irrigation method has been found to be economical compared to other forms of irrigation. Moreover, the method reduces input investment and crop management practices and respective costs through reduced weed growth and limited possibilities of nutrient leaching. Fertilizer components applied are thus utilized efficiently by the crop compared to the other forms of irrigation which are often inefficient in all inputs. Practicing irrigation scheduling using drip irrigation allows farmers to plan on when and how much water to apply in order to achieve a specific level of agronomic performance while ensuring the health of the crop throughout the growing season. Irrigation scheduling also serves as a method of optimizing production while conserving water as much as possible when synchronized with crop water requirement.

Irrigation is often affected by a number of factors such as soil texture depending on the soil type, soil organic matter depending on the amount of soil organic matter present in it, soil depth depending on the amount of sun that reaches its core and the amount of heat absorbed and root depth versus wind speed that would determine the rate of crop evapotranspiration.

Irrigation systems such as overhead irrigation has been found to contribute to leaching of soil nutrients and soil degradation through salinization thus posing environmental concerns alongside water use efficiency (Tilahun *et al*., 2011). Drip irrigation delivers water to the plant roots continuously at a low volume and this helps ensure uniformity of irrigation and germination and minimal losses through evaporation (Dukes *et al*., 2010). Çolak *et al.* (2015) piloted a study to evaluate the Crop Water Stress Index for eggplants using varying drip irrigation regimes. The study focused on the effects of varying irrigation treatments on the growth, quality and yield of eggplant. The study revealed that surface drip irrigation scheduled in an interval of three days had the highest yield of 78.7 t ha^{-1} while subsurface drip irrigation set at six-day irrigation interval produced 40.9 t ha^{-1}. This implies that varying irrigation levels and intervals engenders significant impact on the yield. However, the study emphasized more about fertigation efficiency under drip and overlooked water use efficiency and did not take study cabbage as one of the vegetable crop.

Past studies have shown that the performance of irrigation relies on the interplay of multiple factors that determine its efficiency (Ochieng *et al*., 2016). Soil physicochemical properties such as texture and structure pose significant impact on the performance of irrigation (Ahmadi *et al.*, 2015). Moreover, the type of irrigation system adopted affects the marketable yield of most vegetable crops depending on the set application rates (Fanadzo *et al*., 2010b). A study assessed the effects of broadcasting and fertigation methods of fertilization and the effects of irrigation methods using sprinkler and drip irrigation (Šturm *et al*., 2010). Though there were productivity variations among the methods of irrigation, generally irrigated fields produced the better yield (42.43 t ha^{-1}) compared to non-irrigated experimental fields (19.32 tha^{-1}).

In a different study, Koksal *et al.* (2017) probed the effects of drip and sub-surface irrigation on yield and water use efficiency of capsicum. Their study revealed that drip irrigation schedule S_1 that was based on adding water to field capacity for each schedule gave the highest yield (42.43 t ha^{-1}) and profit. These studies did not evaluate water use efficiency of the selected cabbage varieties or even the economic analysis of the crop. Therefore this proposed study seeks to evaluate the water use efficiency and profitability aspect of these cabbage varieties under micro-irrigation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Site

The research experiment was conducted in the University of Embu Agricultural Demonstration Farm, in Embu County, Kenya. The area is located on Latitude 0^o 30’ S and longitude 37^o 27’ E, at an elevation of 1480 m above sea level (Onyari *et al.*, 2015). Due to its proximity to Mt. Kenya, the County receives an annual mean low and high temperatures of 9 ºC and 28 ºC respectively and an average annual rainfall of 1120 mm (Kisaka *et al*., 2015). The region receives bimodal rainfall and has two major growing seasons whereby the long-rain season is experienced between the months of March and July while the short-rain season ensues from September to December. The soils are mainly *Humic Nitisols* derived from basic volcanic rocks. They are deep, highly weathered with friable clay texture and moderate to high inherent fertility (Jabiol *et al*., 2013).

3.2 Research Design and Layout

The study applied a split plot arranged in Randomized Complete Block Design (RCBD) in which the drip irrigation schedules were allotted the main plot and the crop variety was allocated the sub-plots. There were 12 treatments per block, which comprised of four irrigation schedules, and three cabbage varieties replicated three times. The study field had a total of 36 sub-plots each measuring 3 by 2m meters with a 0.5 m path separating each plot. The crop spacing adopted was 60 by 50 cm. The cabbage test varieties used for this experiment were Riana F_1, Gloria F1 and Triperio F1. The irrigation schedules were organized as follows:

S_1 - Supplemental irrigation applied twice a week to replenish soil water content (SWC) to field capacity (FC).

S_2 - Supplemental irrigation applied once a week to replenish SWC to FC

S_3 - Supplemental irrigation applied after every 2 weeks to replenish SWC to FC

Control - Purely rainfed without supplemental irrigation

The study was conducted in an uncontrolled environment (Plate 1) to simulate the conditions under which majority of smallholder farmers produce the crop.

Field capacity of the study site was determined before the start of the experiment after which soil moisture content was determined before every subsequent irrigation was done. As a result, irrigation water varied depending on the moisture content determined. Moreover, whenever there was rainfall received, the amount of effective rainfall was factored in as the soil moisture could be as high as the field capacity or close to it thus needing no or minimum addition of supplemental irrigation.

Plate 1: Irrigation system layout

3.3 Crop Establishment and Management

Cabbage seedlings were established in a nursery before being transplanted into the experimental plot. The experimental plots were deeply ploughed to ensure good drainage and then harrowed to a fine tilt. The seedlings were transplanted when 4 – 5 weeks old (or with 3 - 4 true leaves). Transplanting was done late in the evening on well-watered planting holes spaced 60 by 50 cm and a planting depth of 2.5 centimeters. Well decomposed farm yard manure and Triple Super Phosphate (TSP) fertilizer was incorporated into the planting hole before planting at the recommended rate of 10 t ha^{-1} and 200 kg ha^{-1} respectively (JICA, 2019). The seedlings were frequently and uniformly irrigated for a period of two weeks to ensure uniform establishment before application of treatments. Apart from irrigation treatments, other management practices were carried out as recommended and uniformly in all the experimental plots (Plate 2). The experiment was conducted for two seasons with the first season running from November 2019 to January 2020 and the second one from February to April 2020.

Plate 2: Already established crop being subjected to irrigation treatments

3.4 Data Collection

Data was collected systematically after every two weeks after transplanting and managed appropriately using MS Excel datasheets. Parameters considered in data collection are discussed in the following sections.

3.4.1 Determination of Soil Chemical Properties

The key soil chemical properties that pose significant effect on the performance of crops were considered in this study by determining their status in the beginning of the study and at the end of the experiment. The rationale was to assess the change of these properties as a result of uptake by the crop (cabbage) under investigation in order to guide the farmer on what elements are likely to be depleted most, despite following the recommended soil amendment practices during production. Soil pH, N-P-K content and the C: N ratio were determined using recommended procedures. Soil samples were collected by traversing the field in a zig-zag pattern and randomly collecting the samples using a soil augur and plastic sampling bags. The collected samples were properly labelled and taken to the University of Embu Chemistry laboratory for analysis.

3.4.1.1 Soil pH

The soil pH was determined using a pH meter (H221, pH/ORP Meter) at the beginning of the experiment to determine the level of acidity of the soil and at the end of the experiment to check for any change in soil pH. The soil samples were analyzed using the procedure described by Eckert & Sims (1995). Twenty (20) grams of the soil sample was measured using a weighing scale and placed into a clean 100 ml beaker and 20 ml of deionized water was the added to the sample before stirring it for about 30 minutes using a digital magnetic stirrer. The sample was then covered and left to stand for an hour to allow cooling to room temperature. The pH meter was calibrated using pH 7.0 and pH 4.0 solutions in order to set the meter within the range of most of the soils. The probe was then rinsed with distilled water and blotted dry before placing it in the soil sample to take the pH reading. Understanding the soil acidity or basicity status is essential in crop farming as it affects availability of essential mineral elements for the crop. Ensuring it's within the level at which the crop can thrive is thus key to growth and production of the target crop.

3.4.1.2 Nitrogen Content

Determination of Nitrogen content was done using the Macro Kjeldahl procedure (Chek, 1999). The process began with digestion of the samples to convert the bonded organic nitrogen in the soil sample into ammonium ions (NH_4^+). To achieve this, 1g of dried and ground soil sample (smaller than 0.5 mm) was weighed and transferred to a digestion tube where it was mixed with 1 gram of catalyst mixture. Ten (10) ml of concentrated suphuric acid was added into the tube and the concoction mixed by swirling to induce segregation. To accelerate the reaction, the flask was sealed with a cotton wool and heated gradually to 100 ^{0}C when frothing started after which the temperatures were raised gradually to 350 ^{0}C. The sample was then allowed to heat until it turned to light green or colorless; which denoted the end of the reaction. The digestion flask was then removed from the heating mantle in the fume hood and allowed to cool under gentle swirling, during which 30 ml of distilled water was added cautiously along the sides of the flask. The contents were then transferred to a 100 ml volumetric flask then topped to the mark with distilled water and the mixture was allowed to stand overnight until the supernatant liquid was clear (Plate 3).

Plate 3: Digested soil samples left to stand overnight

Following digestion, distillation was performed to separate the nitrogen compound (ammonia) from the digested mixture before quantifying the total nitrogen. To accomplish this process, 10 ml of boric acid was added into a clean 100 ml conical flask using a pipette and 3 drops of mixed indicator were added into the same flask. The flask was then placed under the condenser tube of the distillation apparatus while ensuring the tip of the condenser was beneath the surface of the solution (Plate 4). Ten (10) ml aliquot from the clear supernatant of the digested liquid was taken and placed in the distillation apparatus. Using a clean pipette, 10 ml of sodium hydroxide was added and the distillation apparatus were set at 150 ^{0}C to initiate distillation process. The distilled liquid was then mixed with boric acid indicator solution and the color changed from pink to green. The solution was then removed from the distillation setup for titration. Titration process began with the blank being titrated against a diluted standardized 0.007144N H_2SO_4 until the color changed from green to pink.

Plate 4: Sample distillation setup

The nitrogen content in the samples was quantified using function in equation 1:

$$g\ N/litre = g\ NH_4 - N/100g\ soil = (v_s - v_b) * N * 14 * \frac{100*100}{a*b} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where V_s = volume of H_2SO_4 used for the titration of the sample in ml; V_b = volume of H_2SO_4 used for the titration of the blank in ml; N = normality of H_2SO_4 (as found by titration with borax); 14 = equivalent weight of N in g; a = volume of digest taken from distillation (20 ml was used for the samples) and b = weight of the sample taken for analysis in mg.

However, since a sample of 1g (1000 mg) and 10ml of the digest was considered for analysis, the percentage of nitrogen was determined as follows shown in equation 2.

$$\%\ N = (v_s - v_b) * N * 14 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

3.4.1.3 Phosphorus content

Phosphorous levels were determined using Mehlich Double Acid Method (Chek, 1999). A stock solution consisting of a mixture of 4N HCL and 1N H_2SO_4 was prepared by diluting 330 ml concentrated HCL and 28 ml concentrated H_2SO_4 in about 800 ml distilled water, allowing the mixture to cool then filling to a litre mark with distilled water. On the other hand, an extracting solution consisting of a mixture of 0.1N HCL and 0.0025N H_2SO_4 was prepared by diluting 25ml of stock solution in 900 ml distilled water and then topping to a litre mark with distilled water. To prepare soil sample extracts, dried soil was extracted in the ratio of 1:5; mixing 1g of soil with a mixture of 0.1 N HCL and 0.025 N H_2SO_4 solution. Hydrochloric acid served to replace the bulk of the exchangeable metal cations. The sulphate anions in the acid medium replaced the soluble phosphorus available to plants which is held in exchangeable form. The concentration of sulphuric acid was restricted to about 0.03N since the concentration approaches the upper limit of calcium sulphate solubility.

A standard stock solution (500 ppm) was prepared by dissolving 2.196 g of potassium dehydrate orthophosphate in 800 ml extracting solution. Thorough mixing was done then topped to the 500 ml mark with the extracting solution. Six standards were also prepared in six different 100 ml volumetric flasks which were labelled as 0 ppm (blank), 10 ppm, 20 ppm, 30 ppm, 40 ppm and 50 ppm to denote different concentration contained in each of them. Using a pipette, 0 ml, 2 ml, 4 ml, 6 ml, 8 ml and 10 ml of the stock solution was added to the volumetric flasks following the similar order of labeling above. To express the concentration of phosphorus in soil, these standard series solution was determined by multiplying the concentration of P in the above soil extracts with the ration in grams of soil per unit ml of extracting solution (equation 3).

ppm P/100 g = ppm P/100ml solution * 5 ……………………………………. (3)

where: the multiplication factor 5 was derived from the ratio of 5 g of soil to the 25 ml of the extractant (1:5). This therefore implies that the working standard solutions were nominally, 0-5-100-150-200-250 ppm P/100 g soil.

Phosphorus was then determined after 5 ml of the working standard series, soil extract and a blank were transferred into test tubes and mixed with 1ml of ammonium vanadate.ammonium molybdate mixture. Using a colorimeter that had been set at 430 nm an hour before, the density of each solution in the test tubes was read.

3.4.1.4 Potassium content

To estimate the potassium available in the soil, the following reagents were prepared and used in determination process. Anion exchange resin, De- Acidite E by taking 0.5 kg of resin and adding it to 250 ml of 2N NH_4OH. The mixture was then shaken and allowed to settle for about two and half hours. The mixture was then transferred into a funnel fitted with a filter paper and 250 ml of 2N NH_4OH to filter the contents. DW was then used to completely wash the residues until they were free of excess of ammonia. This was denoted by the absence of color development upon adding few drops of phenolphthalein indicator. The residue was then dried at 80 ^{0}C in the oven. Secondly, Ammonium Hydroxide, NH_4OH, 2N was prepared by taking 140 ml of conc. NH_4OH diluting it in 300 ml DW with gentle shaking before topping the solution to a litre mark with DW. 1% Phenolphthalein Indicator was prepared by dissolving 2 g of phenolphthalein in 200 ml of 96% ethanol.

Another solution, Alluminium Chloride. $ALCL_3.6H_2O$, 5% was prepared by dissolving 5 g $ALCL_3.6H_2O$ in 50 ml DW, mixing then filling to 100 ml mark with DW. Lastly, a Mixed Standard Stock Solution, (0.05N Ca, 0.005N K and 0.005N Na) was prepared by weighing 5 g calcium carbonate ($CaCO_3$), 1 g potassium chloride, (KCL) and 1 g sodium chloride, (NaCL). The salts were then dried for two hours at 105^{0}C in an oven after which they were cooled in a desiccator. Using the analytical balance, 2.5 g of $CaCO_3$, 0.373 g KCL and 0.293 g NaCL was measured and dissolved in 800 ml distilled water and 25 ml stock extracting solution. The contents were then filled to a litre mark with DW. Standard Series were also prepared in different concentrations (0, 20, 40, 60 and 80) of the standard stock solutions in different 100 ml volumetric flasks. 1 ml of 5% $ALCL_3.6H_2O$ was added to each and then filled to the mark with extracting solution to make the solution concentrations to 0-0.1-0.2-0.3-0.4 me K.

Similar to phosphorus, to express the concentration of K in soil, the concentration of K in soil extract corresponding to the above standard series were multiplied by the ratio g soil/ml extractant.

me k/100 g soil = me/100 ml solution * 5 ……………………………………. (4)

where: the multiplication factor 5 is derived from the ratio 5 g soil/25 ml extractant (1:5). This gives the working standard series a nominal concentration of 0-0.5-1-1.5-2 K/100 g soil.

To estimate the quantity of potassium in the soil samples, 2 ml of working standard series, soil extract and blank were transferred into clean vials. 5 ml of anion exchange resin and 15 ml DW was then added to each vial. 0.22 ml of 5% of $ALCL_3.6H_2O$ was then added to soil extract followed thorough mixing using a centrifuge and allowed to stand overnight. The working standard series, soil extract and blank solutions were then aspirated into the flame photometer and transmissions recorded. After taking the readings, calibration graphs of transmissions of working standard series were plotted against the concentration of potassium (in me/100 g soil). The concentration of the samples were then read from this graph. Blank reagent corrections were done by subtracting the blank value (known concentration of K) from the sample concentration (with unknown concentration) to determine the concentration of k in each soil sample.

3.4.1.5 C: N Ratio

The C: N ratio was then determined by getting the ratio of the soil organic carbon and nitrogen. Nitrogen data used in this section was pulled from the results determined in the previous tests using Macro Kjedahl procedure. Soil carbon analysis was done at KALRO Muguga Soil Laboratory following Agegnehu *et al.*, 2016 procedure. This was necessitated by the lack of equipment required for carbon analysis at the moment this study was conducted.

3.4.2 Soil Field Capacity and Bulk Density

Central and peripheral sections of the study site were randomly selected after which water was added to saturation point and then left for 48 hours to allow normal drainage to take place. Soil samples were then taken from these sites using standard cores and then subjected to the gravimetric procedure (Tongeren, 1937) to determine the remaining soil moisture content which denoted the field capacity (FC). The soil bulk density was computed by taking the ratio of the dry mass of the soil to the volume of the soil sample used (using the gravimetric procedure). Standard soil cores with known volume were used during sampling so as to determine the bulk density for the dry soil. The following functions were used:

FC = Moisture of wet soil – moisture content of dry soil after 48 hours

Bulk density = Mass of dry soil sample/volume of dry sample

Plate 5: Soil sampling for bulk density analysis

3.4.3 Soil Moisture Content

Soil samples were collected before planting and after every two weeks till the application of the last irrigation schedule. The samples were collected using the soil augur and plastic sampling bags at three depths of 10 cm, 20 cm and 30 cm. This was done to enable identification of the depth at which the crop roots were able to draw water from, based on the soil moisture depletion trend between the three depths and the root depth of cabbage. The wet mass of the sample was weighed and the mass recorded. The sample was then dried in a thermostatically controlled oven for 24 hours at 105 ^{0}C and the new mass was recoded.

Soil moisture readings were taken before and after every irrigation to determine the volume of water that was to be applied to restore the initially determined Field Capacity. A gravimetric method was used to determine soil bulk density (ρ_b), gravimetric water content (w) and volumetric water content (θ) using the following equations:

$$W = \frac{\text{wet mass of soil} - \text{dry mass of soil}}{\text{dry mass of soil}} \quad \text{………………….……..……….Equation 5}$$

$$\theta = w \times \rho_b / \rho_w \quad \text{……………………………………Equation 6}$$

Additionally, Crop Evapotranspiration was computed by water balance equation

$$[P+I = ET + D + R \pm \Delta S] \rightarrow ET = (P + I) - (D + R \pm \Delta S) \text{…….. Equation 7}$$

Where, P- Precipitation, I- Irrigation, ET- Evapotranspiration, D-Deep percolation, R-Runoff and ΔS- change in soil moisture content.

However, according to Chapter 6 of FAO on drip irrigation (Brouwer, *et al.,* 1988), the drip irrigation system mode of delivery is controlled and thus not expected to loss water through deep percolation and runoff. Since this study used drip irrigation method, losses to deep percolation and runoff were deemed negligible and thus omitted from the equation. The study thus used the following equation to calculate ET:

$P + I = ET \pm \Delta S \rightarrow ET = P + I \pm \Delta S$……………………………………………Equation 8

The percent soil moisture content (% MC) was then determined using the following formula:

% Moisture is $\frac{Loss\ in\ moisture}{Oven-dry\ Weight}$………………………………………….........Equation 9

The irrigation water required for each irrigation schedule was determined using the following formula:

Required irrigation = [%FC - %MC] x d…………………………………….…. Equation 10

Where'd' was the root zone depth.

3.4.4 Determination of Crop Water Requirement

The amount of irrigation water used during the growing period was measured by taking readings before and after each irrigation schedule. The difference was the amount added for that irrigation schedule and this volume was determined by getting the soil water content for each subsequent irrigation schedule followed by calculation of the deficit from the field capacity. In case of rainfall, precipitation data from the local weather station (KALRO Meteorological station which was within the recommended 500 m diameter from the experiment) was used to account for rain water added using the water balance equation as described in Equation 6.

$[Pe + I = ET + Dp + R \pm \Delta S] \rightarrow ET = (Pe + I) - (Dp + R \pm \Delta S)$……..………. Equation 11

where; I is irrigation water, Pe is effective precipitation, ΔS is the soil water content, Dp: is deep percolation, ET is evapotranspiration and R is runoff (Fan *et al*., 2014). However, since water application by drip irrigation is controlled, deep percolation and runoff were deemed to be insignificant hence not included in the calculation. Consequently, the following equation was adopted for this study;

$$[Pe+I = ET \pm \Delta S] \rightarrow ET = (Pe + I) - (\pm \Delta S) \quad \text{…………………….…….. Equation 12}$$

3.4.5 Computation of Water Use Efficiency and Water Productivity

Water use efficiency (WUE) per variety was determined using the following equation:

$WUE = (ETc)/\text{total water applied}$…………………………………….……… Equation 13

Where; total water applied was determined as rainfall + irrigation water and ETc is amount of water productively used (Manderscheid *et al.,* 2018).

$ETc = (Pe + I) \pm \Delta S$

Water productivity (WP) was determined as:

$WP = \text{Yield (kg/ha)}/ETc \text{ (mm)}$ ……………………………………………… Equation 14

3.4.6 Maturation Time

The study assessed the physiological maturity of the cabbages using Rizzolo and Zerbini (2012) recommendation for leafy vegetables. The indices used include head size, firmness and compactness. A scale of 1 to 4 was used to score cabbage maturity as shown in Table 3.1. Maturity was determined when 50% of the cabbage heads became compact and solid (score 3). The time to maturity was scored by recording the number of weeks taken for 50% of the cabbages per subplot to mature.

Table 3.1: Cabbage Maturity Assessment Scale

Score	Rating scale	Firmness description
1	Soft	Spongy, easy to compress
2	Firm	Compact but slightly compressible
3	Hard	Compact and solid (recommended)
4	Extra hard	Over-mature

3.4.6.1 Cabbage Disorders

The two major cabbage disorders (tip burn and head splitting) which are associated with water stress were also used to assess market quality as their presence depicted a direct effect on gross margin. Tip burn is a disorder in cabbage that is caused by limited and/or excessive soil moisture that reduces oxygen levels in the soil thus reducing calcium uptake. This disorder can be noted with the presence of brown to black necrotic leaf tips (Inthichack, *et al.*, 2012). On the other hand, cabbage splitting is caused by application of excess water during the late stages of cabbage development, when the head is already firm. The two disorders were scored as 0 for non-occurrence and 1 for occurrence (Olle and Williams, 2017).

Plate 6: Head splitting disorder of cabbage

3.4.7 Stand Count and Yield

The stand count of cabbage per plot was determined by counting the total number of marketable cabbages at maturity. The cabbage head weight was determined by weighing on a digital scale balance. Cabbages (6) from the middle rows of the experimental plots were harvested and weighed. The area of the experimental plot was used to calculate the yield of the crop in kg ha^{-1} (Begna and Damtew, 2015).

3.4.8 Economic profit Analysis

The study adopted the accounting profit model as described by O'Leary *et al.* (2018) to assess the profitability of each variety and individual irrigation schedule. This model factors in revenue generated and the explicit costs incurred. In this study, explicit costs include the cost of water, drip kit, cabbage seedlings, fertilizer, manure, labor (from nursery preparation, land preparation, experimental design layout, crop management and harvesting) and agro-chemicals (duduthrin, alpha and escort) used. The cost of land was not factored in as it varies with location and thus could not give a significant error to this study. Moreover, the study aimed at local farmers who often own individual units of land thus including this cost could increase the production cost than they could incur. Net revenue was computed using the function;

Net Revenue = Gross Revenue – Total cost………………………………….. Equation 15

Revenue was determined using the farm-gate pricing and the total quantity produced.

3.5 Data Analysis

Data collected was analyzed using SAS computer Software (V.9.4). A two-way ANOVA was used to assess whether there were significant variations and interactions between different varieties and irrigation schedules on growth and yield of cabbage in every season. Further, a combined season analysis was conducted using a three-way ANOVA to assess the seasonal variations and interactions between seasons, different varieties and irrigation schedules. Treatment means were separated using SNK test at 95% level of confidence. Pearson correlations were done to assess the relationship between irrigation parameters (quantity of water added, water use efficiency and water productivity) with yield components (growth, stand count, disorders, maturity period and marketable yields).

CHAPTER FOUR
RESULTS

4.1 Weather Data

Weather conditions during the study period were erratic whereby the amount of precipitation experienced was mostly ineffective; below 5 mm (Ali & Mubarak, 2017) (Table 4.1). During the first two months of the first season (December 2019 and January 2020), high levels of precipitation were experienced, after which a drought spell followed until the end of the season. In the second season (May to July 2020), light rainfall was experienced in the month of May after which drought again ensued. The changes in the amount and distribution of rainfall within the region would be attributed to the effects of climate change. Daily and monthly mean temperatures were fairly similar across the two seasons, although higher mean temperatures were recorded in the first season as in comparison with those recorded in the second season (Table 4.1).

Table 4.1: Weather data recorded during the growing periods of 2019 and 2020

Season	Month	Rainfall (mm)	Mean Temperature (^oC)	Mean Relative Humidity (%)
1	Dec, 2019	23.57	20.45	85
	Jan, 2020	32.87	20.94	83
	Feb, 2020	0.56	21.56	79
2	May, 2020	2.06	20.34	87
	Jun, 2020	0	18.94	85
	Jul, 2020	0	18.17	84

4.2 Soil Physicochemical Properties

The results on the various soil chemical properties assessed indicated some changes on some of the soil properties during the experiment while some remained stable (Table 4.2). There was a slight increase of the bulk density from 1.039 g/cm^3 (before the experiment) to 1.060 g/cm3 (after the experiment). Soil acidity also increased from 5.17

to 5.11 probably due to the DAP fertilizer used in the study. Soil organic carbon and percentage of nitrogen in the soil remained unchanged at 2.10% and 0.19% respectively. Soil phosphorus and potassium elements also showed slight increments. Potassium levels in the soil increased from 0.74% to 1.09% while phosphorus increased from 64.33 ppm to 89.33 ppm.

Table 4.2: Soil Physicochemical findings before and at the end of production seasons

	Sample	N %	P (ppm)	K (meq %)	SOC%	C:N	SOIL pH	BDgcm^{-3}
Base	1	0.21	55.00	0.62	2.2	10.90	5.53	1.13
line	2	0.19	102.00	0.88	2.18	11.47	5.10	1.09
	3	0.18	52.00	0.76	2.07	11.50	5.26	1.03
	4	0.20	59.00	0.72	2.17	10.85	4.88	0.95
	5	0.18	62.00	0.71	1.74	9.67	5.16	0.97
	6	0.19	56.00	0.73	2.12	11.16	5.07	1.08
Mean		0.19	64.33	0.74	2.10	10.93	5.17	1.04
End-	1	0.21	89.00	1.16	2.36	11.24	5.01	1.05
line	2	0.18	79.00	1.30	2.09	11.61	5.27	1.04
	3	0.20	125.00	1.38	2.21	11.05	5.34	1.07
	4	0.19	84.00	1.08	2.13	11.21	5.20	1.11
	5	0.16	52.00	0.78	1.81	11.31	4.75	1.08
	6	0.20	107.00	0.84	1.97	9.85	5.11	1.00
Mean		0.19	89.33	1.09	2.10	11.05	5.11	1.06

Legend: N- nitrogen, P- phosphorus, K- potassium, BD- bulk density and C: N ratio of soil carbon to nitrogen in the soil.

4.3 Irrigation Water Supplied

The amount of irrigation water applied in every irrigation schedule in season I was not significantly ($p > 0.05$) different to the amount supplied in the second season (Figure 4.1). Rainfall received during the first growing season was higher and well distributed within the first two months of growing unlike season II that hardly received any significant amount of rainfall, thus demanding more supply of irrigation water. There were significant differences ($p < 0.05$) in the amount of irrigation water added in different irrigation schedules (Figure 4.1) to replenish the soil moisture to field capacity. In the first season, the S1 received the highest addition of water of 1,283.57 m^3/ha while S4 received the lowest amount (553 m^3/ha) which was purely from rainfall. There was no significant ($p > 0.05$) difference in the amount of irrigation water that was added in S2 and S3 irrigation schedules which amounted to 965 m^3/ha and 905 m^3/ha, respectively. In the second season, S1 received the highest amount of water totaling 1,443 m^3/ha while S4 received the lowest amount of 198 m^3 ha^{-1}, respectively. Similar to season I, there was no significant ($p > 0.05$) difference in the amount of irrigation water that was added in S2 and S3 irrigation schedules in season II, which amounted to 907 m^3 ha^{-1} and 808 m^3 ha^{-1} respectively.

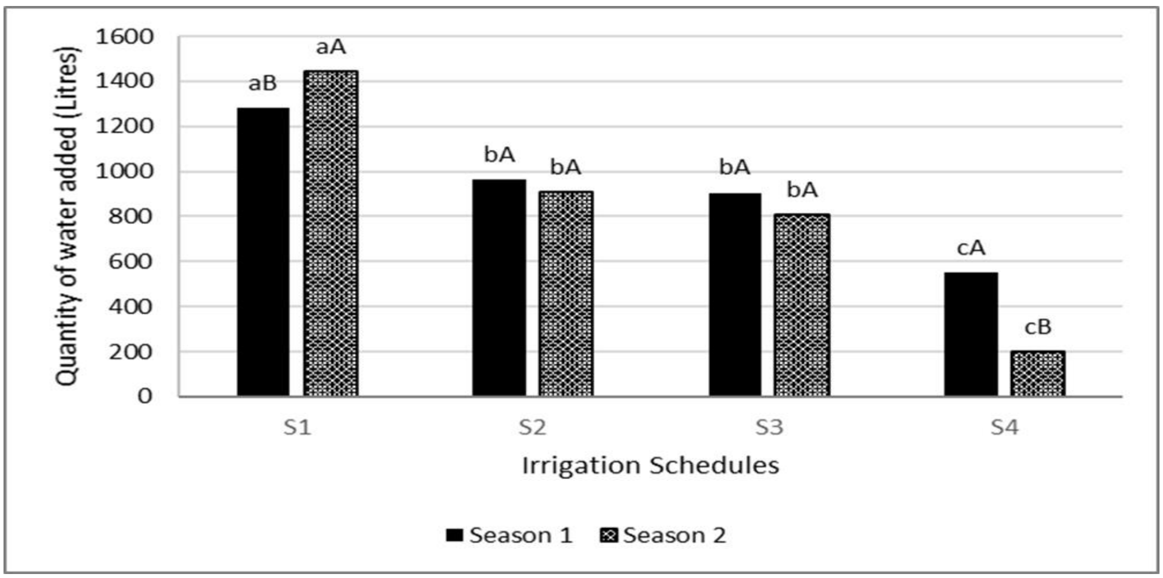

Figure 4.1: Cumulative quantity of irrigation water added in the four irrigation schedules (S1, S2, S3 and S4) during the study period. The small letters represent treatment variations while the capital letters represent seasonal variations per treatment

4.4 Water Productivity & Water Use Efficiency

Drawing from the results obtained (Table 4.3) during the first season of the experiment, there were significant ($p < 0.05$) differences on water productivity between S3 and S4 irrigation schedules. However, there were no significant ($p > 0.05$) differences between S1, S2, and S3 irrigation schedules. The fourth irrigation schedule (S4) had the highest water productivity of 61.36 kg m^{-3} while the least water productivity was realized with the twice a week irrigation schedule (S1). The weekly irrigation schedule (S2) and the fortnightly schedule (S3) ranked second and third best respectively in terms of water productivity (Table 4.3). According to LSD, water productivity difference below 7.64 among the irrigation treatments was considered insignificant. During the second season, similar trends to those in season I were witnessed though with slight increments on water productivity and water use efficiency as depicted in the results. The changes were attributed to low rainfall received in the second season, higher evapotranspiration, and limited water/moisture content compared to the first season. The control treatment (S4) had the highest water productivity of 125 kg m^{-3} while the first irrigation schedule (S1) recorded the least water productivity (68.10 kg m^{-3}). The second irrigation schedule (S) and the third irrigation schedule (S3) ranked third and fourth respectively as shown in table 4.3.

With cabbage cultivars, there were no significant ($p < 0.05$) variations observed between variety 1 (Gloria), variety 2 (Riana) and variety 3 (Triperio). On overall, variety 1 (Gloria) had the highest water productivity (87.09 kg m^{-3}) followed by variety 2 (Riana) and variety 3 (Triperio) (80.93 and 75.43 kg m^{-3}) respectively. In summary, the mean water productivity was better/higher in season II 81.15 compared to 55.25 kg m^{-3} realized in season I. The water use efficiency was significantly ($p < 0.05$) different across the four irrigation schedules in both seasons with the least significant difference of 0.01 for both seasons. The control treatment recorded the highest water use efficiency of 0.70 and 0.77 in the first and second seasons respectively. The irrigation schedule which received water once biweekly (S3) was second in both season I and II with 0.53 and 0.63 respectively. The irrigation schedules that received water once (S2) and twice a week (S1) in both seasons ranked third and fourth respectively as indicated in table 5 below. However, there were no significant ($p > 0.05$) differences among the cabbage cultivars tested, with the least significant difference of 0.24 and 0.17 in the first and second seasons, respectively. Similar to water productivity, water use efficiency was higher in season II (0.60) compared to season I (0.54).

Table 4.3: Water Productivity and Water Use Efficiency analysis for drip irrigated cabbage varieties over different irrigation schedules

		Season I		Season II	
Treatment	Factor	WP ($kgha^{-1}mm^{-1}$)	WUE	WP ($kgha^{-1}mm^{-1}$)	WUE
Irrigation Schedules	S1	54.83^{ab}	0.46^{d}	68.10^{c}	0.49^{d}
	S2	55.28^{ab}	0.47^{c}	88.43^{b}	0.50^{c}
	S3	49.53^{b}	0.53^{b}	42.55^{d}	0.63^{b}
	S4	61.36^{a}	0.70^{a}	125.51^{a}	0.77^{a}
	LSD	7.64	0.01	14.35	0.01
Cabbage Variety	Gloria	54.76^{a}	0.54^{a}	87.09^{a}	0.60^{a}
	Riana	56.66^{a}	0.54^{a}	80.93^{a}	0.59^{a}
	Triperio	54.33^{a}	0.54^{a}	75.43^{a}	0.59^{a}
	LSD	6.62	0.24	12.43	0.17
	R^2	0.58	0.99	0.86	0.99
	CoV	14.32	1.04	18.32	1.58
	Mean	55.25	0.54	81.15	0.60
	Interactions (I*V)	n.s	<.0001	n.s	<.0001

Legend: Means followed by the same letter within a column are not significantly different. R^2 – Coefficient of Determination; CoV – Coefficient of Variation; NS – Not Significant

4.5 Cabbage Growth and Yield

Growth parameters assessed included time to maturity, cabbage stand count (number of heads per ha) and yields per ha (in tons) (Table 4.4). In the first season, the cabbages grown under S1 took the shortest period of 9 weeks to attain maturity which was significantly ($p < 0.05$) different from the 11 weeks taken under S2 and 15 weeks taken by cabbages under S3 and S4 treatments to attain maturity. An analogous trend was witnessed in the second season although growth was slightly enhanced under S3 and S4 in the second season where the cabbages took 13 and 14 weeks respectively to attain maturity. Time taken to attain 50% maturity among the cabbage varieties investigated did not have significant ($p > 0.05$) differences. Consequently, there was no interaction between irrigation schedule and cabbage variety on time taken to maturity. On average, time to maturity was estimated to be 12 weeks from time of transplanting.

4.6 Cabbage Stand Count

In both seasons, irrigation schedules S1, S2 and S3 were not significantly ($p > 0.05$) different in the number of heads per hectare, which averaged 3547 and 2817 heads per hectare in season I and II respectively. However, S1 and S2 were significantly ($p > 0.05$) different in head count from S4 in season I while S1 was significantly ($p < 0.05$) different in head count from S4 in season I (Table 4.4). The cabbage varieties had no significant ($p > 0.05$) differences on the number of heads per hectare, which averaged 3072 and 2440 heads per hectare in season I and II respectively. This implied that the tested cultivars had similar establishment characteristics under similar conditions. There was no interaction between irrigation schedule and cabbage variety on the stand count in both seasons.

4.7 Cabbage Yield

The cabbage yield was obtained by measuring the cumulative fresh weight in kilogram of each cabbage variety per experimental plot and then converting the data to yields in tons per hectare. There were significant ($p < 0.05$) differences in the marketable yield of harvested cabbages across all the irrigation schedules (Table 4.4). The least significant difference (LSD) for yield during the first and second season was 6.25 and 5.41 t ha^{-1} under irrigation treatment and 5.95 and 5.15 t ha^{-1} under varietal treatment respectively. In the first season, S1 gave the highest yield (67.58 t ha^{-1}) followed by S2 (53.05 t ha^{-1}), then S3 (43.75 t ha^{-1}). The control plot (S4) produced the lowest yields of 33.69 t ha^{-1}. Similarly, in the second season, S1 gave the highest yield of 64.99 t ha^{-1} followed by S2 (53.09 t ha^{-1}), S3 (22.75 t ha^{-1}), and S4 (16.45 t ha^{-1}). The cabbage varieties did not differ significantly ($p > 0.05$) in yield and there was no interaction between supplemental irrigation and cabbage variety in terms of yield (Table 4.4).

Table 4.4: Growth and yield response of different cabbage varieties to different drip irrigation schedules

		Season I			Season II		
		Weeks to 50%	No. of Heads/Ha	Yield (tha^{-1})	Weeks to Maturity	No. of Heads/Ha	Yield (tha^{-1})
Treatment	Factor	Maturity					
Irrigation schedule	S1	9^{c}	$29,815^{a}$	67.58^{a}	9^{c}	$31,296^{a}$	64.99^{a}
	S2	11^{b}	$27,778^{a}$	53.05^{b}	11^{b}	$29,444^{ab}$	53.09^{b}
	S3	15^{a}	$26,481^{ab}$	43.75^{c}	13^{a}	$29,259^{ab}$	22.75^{c}
	S4	15^{a}	$23,519^{b}$	33.69^{d}	14^{a}	$27,037^{b}$	16.45^{d}
	LSD	1	3547	6.25	1	2817	5.95
Cabbage variety	Gloria	11^{a}	$27,778^{a}$	49.04^{a}	12^{a}	$30,000^{a}$	40.60^{a}
	Riana	12^{a}	$27,083^{a}$	51.49^{a}	12^{a}	$29,167^{a}$	41.01^{a}
	Triperio	12^{a}	$25,833^{a}$	48.02^{a}	12^{a}	$28,611^{a}$	36.35^{a}
	LSD	1	3072	5.41	1	2440	5.15
	R^2	0.81	0.51	0.89	0.79	0.46	0.94
	CoV	12.12	13.49	12.91	8.73	9.85	15.66
	Mean	12	26,898	49.52	12	29,259	39.32
Interactions		NS	NS	NS	NS	NS	NS

Legend: Means followed by the same letter within a column are not significantly different. R^2 – Coefficient of Determination; CoV – Coefficient of Variation; NS – Not Significant

4.8 Profitability of cabbage across treatments

The production cost incurred in both seasons was similar for specific cabbage varieties and specific irrigation schedules but application of different irrigation schedules resulted in significantly ($p < 0.05$) different production costs (Table 4.5). Cost difference above least significant difference of $25.98 was considered significant. Irrigation schedule 1 (S1) resulted in the highest production cost of $2,103 per hectare per season followed by S2, S3 and S4 with production costs of $1,992, $1966, $1,854 per hectare per season respectively. The potential net revenue realizable from the sale of cabbage obtained from the different irrigation schedules was significantly ($p < 0.05$) different with S1 producing the highest revenue and S4 giving the lowest revenue in both seasons (Table 4.5). There were significant ($p < 0.05$) differences in net revenue from the different cabbage varieties in the first season but there were no significant ($p > 0.05$) differences observed among different cabbages in the second season (Table 4.5) and in combined season analysis.

Table 4.5: Profitability analysis for drip irrigated cabbage varieties over different irrigation schedules

Factor		Season I		Season II	
		Production Cost (USD)	Net Revenue (USD)	Production Cost (USD)	Net Revenue (USD)
Irrigation schedule	S1	2,103[a]	5,947[a]	2,103[a]	4,460[a]
	S2	1,992[b]	3,443[b]	1,992[b]	2,872[b]
	S3	1,966[c]	2,903[b]	1,966[c]	2,753[b]
	S4	1,854[d]	1,575[c]	1,854[d]	2,011[c]
	LSD	25.98	819.82	25.98	692
Cabbage variety	Gloria	1,959[a]	3,853[a]	1,959[a]	3,033[a]
	Riana	1,959[a]	3,519[ab]	1,959[a]	3,302[a]
	Triperio	2,019[b]	3,028[b]	2,019[a]	2,737[a]
	LSD	59.56	709.9	59.65	599.4
	R^2	1	0.86	1	0.69
	CoV	0	24.19	0	23.70
	Mean	1,979	3,467	1,979	3,024
Interactions		NS	NS	NS	NS

Legend: Means followed by the same letter within a column are not significantly different. R^2 – Coefficient of Determination; CoV – Coefficient of Variation; NS – Not Significant

4.9 Pearson Correlation Analysis

There were both positive and negative relationships between the irrigation parameters and the yield components assessed. Irrigation water moderately and negatively correlated with water productivity (-0.556), but strongly and negatively correlated with water use efficiency (-0.879) and maturity period (-0.765) of the cabbages. Nonetheless, there was a moderately and positively correlation between the irrigation water supplied and cabbage head splitting (0.538), stand count (0.543). The correlation was stronger and positive with yield (0.825) and net revenue (0.749). Water use efficiency strongly and positively correlated with maturity period (0.740), yield (0.853) but moderately and positively correlated with cabbage splitting (0.636) and net revenue (0.582). However, water use efficiency had a negative strong (-0.905) and moderate (-0.460) correlation for irrigation water and stand count respectively (Table 4.6).

Correlation between maturity period was strong and negative with irrigation water (-0.720) but moderate and negative with cabbage splitting (-0.447) and net revenue (-0.566). The correlation was however strong and negative between maturity period and yield (-0.852). There was a moderate and positive correlation between maturity period and water use efficiency (0.643). Tip burn disorder of cabbage moderately and positively correlated with water use efficiency (0.593) but correlated weakly and positively with maturity period (0.377). Still, there was a moderate and negative correlation between maturity period and irrigation water (-0.574). Cabbage splitting disorder strongly and positively correlated with irrigation water used (0.720), yield (0.718) but correlated moderately and positively with stand count (0.494) and net revenue (0.569). Nonetheless, there was a strong and negative correlation between the splitting disorder and water use efficiency (-0.706). The correlation was however weakly and negatively with maturity period (-0.472) and tip burn disorder (-0.378) (Table 4.6).

Similarly, stand count moderately and positively correlated with irrigation water (0.665), cabbage splitting (0.521), yield (0.513) and net revenue (0.609). It however moderately and negatively correlated with water use efficiency (-0.666), maturity period (-0.471) and tip burn disorder of cabbage (-0.469). Yield strongly and positively correlated with irrigation water (0.805), stand count (0.774) and net revenue (0.700) (at $p>0.001$ level of significance) but had a moderate and positive correlation with cabbage splitting disorder (0.624) (at $p>0.001$) and water productivity (0.397) at $p>0.05$ level of significance.

Table 4.6: Pearson correlation matrix between irrigation parameters and cabbage yield components for separate seasons

Variables	Irrigation Water	WP	WUE	Maturity Period	Tip Burn	Cabbage Splitting	Stand Count	Yield	Net Revenue
Irrigation Water	**1**	**-0.556*** **	**-0.879*** **	**-0.765*** **	-0.236	**0.538*** **	**0.543*** **	**0.825*** **	**0.749*** **
WP	-0.205	**1**	**0.434** **	0.121	0.131	0.015	-0.125	-0.054	-0.261
WUE	**-0.905*** **	0.257	**1**	**0.740*** **	0.169	**-0.636*** **	**-0.460** **	**-0.853*** **	**-0.582*** **
Maturity Period	**-0.720*** **	0.014	**0.643*** **	**1**	0.053	**-0.511*** **	**-0.447** **	**-0.852*** **	**-0.566*** **
Tip Burn	**-0.574*** **	0.090	**0.593*** **	**0.377* **	**1**	-0.239	-0.215	-0.216	-0.195
Cabbage Splitting	**0.720*** **	-0.099	**-0.706*** **	**-0.472** **	**-0.378* **	**1**	**0.494** **	**0.718*** **	**0.569*** **
Stand Count	**0.665*** **	0.188	**-0.666*** **	**-0.471** **	**-0.469** **	**0.521*** **	**1**	**0.513*** **	**0.609*** **
Yield	**0.805*** **	**0.397* **	**-0.711*** **	**-0.653*** **	**-0.501** **	**0.624*** **	**0.774*** **	**1**	**0.700*** **
Net Revenue	**0.858*** **	-0.044	**-0.709*** **	**-0.702*** **	**-0.472** **	**0.746*** **	**0.604*** **	**0.768*** **	**1**

Values in bold are different from 0 with a significance level of 0.05*; 0.01**; 0.001***. The lower data is for season I while the upper data is for season II.

Water use efficiency, maturity period and tip burn negatively correlated with yield with -0.711, -0.653 and -0.501 scores respectively (Table 4/6). Lastly, net revenue strongly and positively correlated with irrigation water (0.858), cabbage splitting disorder (0.746) and yield (0.768) at a significance level of p>0.001. A moderate and positive correlation was observed between stand count and revenue at 0.604 with a significance of p>0.001. However, there was a negative correlation between net revenue against water use efficiency (-0.709) and maturity period (-0.702) at p>0.001 and tip burn (-0.472) at p>0.01 significance level.

The Pearson correlation coefficients from Table 4.7 indicate that irrigation water significantly and negatively correlated with water productivity (-0.488_, water use efficiency (-0.869), maturity period (-0.665) and tip burn (-0.343) in both seasons. However, there were positive correlations between irrigation water and cabbage splitting (0.591), stand count (0.451), yield (0.813) and net revenue (0.717) from both production seasons.

From the two seasons, water productivity significantly correlated with water use efficiency only with a positive correlation coefficient of 0.431. On the other hand, water use efficiency significantly and positively correlated with maturity period (0.635) and tip burn (0.344) but negatively correlated with cabbage splitting (-0.687), stand count (-400), yield (-0.810) and net revenue (-0.635) in both seasons. Likewise, tip burn had significant weak and negative correlation with cabbage splitting (-0.293), stand count (-346), yield (-0.309) and net revenue (-0.349). Maturity period significantly and positively correlated with tip burn (0.243) but negatively correlated with cabbage splitting (-0.462), stand count (-0.435), yield (-0.673) and net revenue (-0.653). Yield correlated positively with net revenue (0.686) while stand count positively correlated with yield (0.440) and net revenue (0.502). There were also significant and positive correlations observed between cabbage head splitting and stand count, yield, and net revenue with correlation coefficients of 0.357, 0.687 and 0.674 respectively (Table 4.7).

Table 4.7: Pearson correlation matrix between irrigation parameters and cabbage yield components for both seasons combined

Variables	Irrigation Water							
WP	**-0.488*** **	WP						
WUE	**-0.869*** **	**0.431*** **	WUE	Maturity Period				
Maturity Period	**-0.665*** **	0.056	**0.635*** **					
Tip Burn	**-0.343** **	0.084	**0.344** **	**0.243* **	Tip Burn	Cabbage Splitting		
Cabbage Splitting	**0.591*** **	-0.121	**-0.687*** **	**-0.462*** **	**-0.293* **		Stand Count	
Stand Count	**0.451*** **	0.150	**-0.400*** **	**-0.435*** **	**-0.346** **	**0.357** **		
Yield	**0.813*** **	-0.096	**-0.810*** **	**-0.673*** **	**-0.309** **	**0.687*** **	**0.440*** **	Yield
Net Revenue	**0.717*** **	-0.193	**-0.635**	**-0.652*** **	**-0.349** **	**0.674*** **	**0.502*** **	**0.686*** **

Values in bold are different from 0 with a significance level of 0.05*; 0.01**; 0.001***.

CHAPTER FIVE

DISCUSSION

5.1 Weather Data

The experiment was conducted in two seasons where weather variations were observed based on the season of the year. Rainfall in the first season was relatively higher to that of the second season of production because the first season coincided with the short rains season for the region while the latter coincided with the dry season of the year when rainfall is erratic and often ineffective (Gateri, 2015). Relative humidity and temperature were also relatively higher in the first season than the second season. The low relative humidity in the second season is attributed to the low rainfall received during the production cycle while the low temperatures were in accordance to the weather conditions experienced in the region mid-year (Gummadi *et al*., 2020)

5.2 Soil Physical & Chemical Properties

Soil chemical properties are key indices for soil fertility status that directly translate to production (Mairura *et al.,* 2007). Assessing their state in the soil is thus significant in ensuring proper soil management is done to improve its productivity. The current study sought to assess how these soil chemical properties shifted during the production period so as to provide some insights on whether irrigation scheduling affected nutrient depletion from the soil either through leaching or absorption. The goal for this was to advice the farmers on which type of irrigation scheduling to consider for optimum cabbage production while taking into account the depletion of the macro elements depletion in the soil.

Drawing from the results, it’s evident that the C:N ration and the macro elements assessed were unchanged even after production cycle and those that changed, they did not indicate significant amounts to trigger a shift in yield. This may be attributed to the fact that the key elements required by cabbage were supplied through application of well decomposed farm yard manure and triple super phosphate (TSP) fertilizer before planting in each season at the recommended rate of 10 tha^{-1} and 200 $kgha^{-1}$, respectively. Fanadzo *et al.* (2010b) recommended that for optimum production on nitisols, application of inorganic fertilizer and manure should be considered. The ratio of these elements is very crucial factor considered in production as it influences the soil functioning particularly nutrient cycling through crop residual decomposition and optimum functioning of soil microbes. Carbon here serves as the source of energy and also provides the basic building blocks that constitute 50% of the mass of a microbial cell. Nitrogen on the other hand provides nucleic acid, proteins, amino acids, enzymes and co-enzymes that are necessary for the growth and functioning of a microbial cell. The results also indicate that the average bulk density slightly increased from 1.04 to 1.06g cm^{-3} and this is attributed to compaction resulting from use of farm machinery during land preparation.

The findings indicate that the highest soil pH was 5.53 and lowest at pH 4.75, giving an average pH level of 5.17. The observed pH range corroborates with a pH characteristic of *humic nitisols,* which is less than 5.5 due to leaching of soluble bases. According to Liu and Hanlon (2012), ideal soil pH for cabbage production should be between 4.5 and 6.5 so as to avoid leaf darkening and death from leaf margins. The pH range from the current study fell within this range and therefore production of the crop occurred within the acceptable limits of soil acidity. This also implies that soil acidity was not a limiting factor in this study. The slight increase of bulk density was attributed to the tramping during land preparation and data collection.

5.3 Water Productivity & Water Use Efficiency

The current study was undertaken to explore the impact of drip irrigation scheduling practice on water productivity so as to improve productivity of scarcely available resources (land and water). This study is essential in this era of climate change as it seeks to address issues of food security and improvement of household standards of living through enhanced water productivity. The findings of this study revealed that water productivity increased with decrease in the amount of irrigation water supplied. This was attributed to increased utilization of limited water received by the crop for survival and growth.

Although the S4 schedule (irrigation treatment where water was supplied once fortnightly) gave the highest water productivity, it cannot be recommended without consideration of the other parameters such as yield and revenue. Integrating these factors, S4, despite having high water productivity is not economically feasible to adopt when production (yield) is the key consideration. This is because the crops under the treatments gave the lowest yield since they were deprived of sufficient water required for them to thrive. A study by Greaves & Wang (2017) that investigated crop water productivity of irrigated maize postulated that water productivity determined with respect to the amount of water applied is directly equivalent to economic crop water productivity. This implies that by focusing on the economic returns of crop production as the key objective of farmers/ producers, S4 cannot be recommended. The study also highlighted that compelling farmers to adopt an irrigation schedule with the best water productivity (S4 in this case) remains a challenge to stakeholders.

A study by Perry *et al. (*2009) revealed that water productivity of irrigated crops is higher compared to that of rain-fed crops in unindustrialized countries, but then lesser in industrialized countries. This infers that there is a significant untapped potential to increase water productivity through adoption of efficient resource use approaches such as irrigation scheduling in food production among sub-Saharan Africa that can translate to increased food production in the region than relying on rain-fed agriculture. Another study by Singh & Nautiyal, (2017) that investigated the world water productivity situation reported that water productivity increase proportionally with increased efficiency of water. This is evident with the current study where the cabbages under the control treatment (S4) recorded the highest water productivity and water use efficiency compared to cabbages grown in plots under the irrigation schedules with higher watering frequencies.

This study adhered to the latest definition of water productivity and water use efficiency as defined by the FAO (2017). According to FAO, water use efficiency refers to the proportion of the effective water use to the actual water withdrawal. On the other hand, the FAO defines water productivity as a measure of the economic or biophysical addition from the use of a unit of water consumed in crop production (yield/output/unit input/water). Therefore, past literature on water use efficiency was compared to water productivity finding in this study because, despite the change in definition and formula, they both use the same procedure in their determination.

A study by Shanarappa *et al.* (2000) which investigated water use efficiency and yield of cabbage as influenced by drip and furrow methods of irrigation reported that Water Productivity of 41.89 kgm^{-3} and 27.90 kgm^{-3} was obtained when irrigation was performed twice a week and once a week respectively. This is lower compared to water productivity of 55.25 kgm-3 and 81.15 kgm^{-3} realized in the current study where irrigation was performed twice and once a week respectively. The marked differences observed in the two studies is attributed to different weather and soil conditions under which the two experiments were performed. The current study was performed under *humic nitisols* which are deep, highly weathered with friable clay texture and moderate to high inherent fertility (Jabiol *et al*., 2013). These characteristics perhaps ensured higher water retention and water productivity compared to sodic vertisols under which the other experiment was performed. Sodic vertisols are highly basic, poor in organic matter and have poor physical conditions, which limit their water retention capacity and productivity (Ghosh *et al.,* 2010).

An appraisal on approximation of crop water requirement, irrigation frequency and water use efficiency of cabbage production by Beshir, (2017) also recommended twice a week irrigation as more feasible for cabbage production. Another investigation by Nyatuame *et al.* (2013) on irrigation scheduling and water use efficiency on cabbage yield revealed that water productivity increased inversely proportional to the amount of irrigation water applied. In their study, irrigation twice a week resulted to a water productivity of 35.48 kgm^{-3} which was lower compared to 54.83 kgm-3 obtained in the current study. However, irrigation once a week resulted to a water productivity of 58.72 kg m^{-3} which compared to 55.28 kgm^{-3} determined in the current study. The differences here are also attributed to contrasting production conditions. The experiment by Nyatuame *et al.*

(2013) was conducted in achrosols and lithisols whose chemical characteristics are totally different to the conditions in *humic nitisols* where the current study was conducted.

A study by Tiwari *et al.* (2020) on water productivity and yield as affected by drip irrigation rate and irrigation schedule reported a yield of 18.57 $Mgha^{-1}$. Comparing her results and the current findings, they depict a reduction of yield compared with the twice a week schedule adopted by the current study. Though, the study by Tiwari *et al.* (2020) reported a reduced yield with daily irrigation regime, the cabbage cultivars, agro-ecological characteristics and soil types in these two studies were different and therefore there is need to assess the effect of more frequent irrigation schedules under *humic nitisols* of Embu County.

5.4 Growth and Yield of Cabbages

Production and achievement of optimum marketable yield of cabbages is greatly anchored on the amount of water available to the crop, owing to its intensive water requirement among other resources. Establishing the best level of irrigation that can be adopted and used to optimize on the yield and economic returns while minimizing on the production cost is key (Ali & Talukdar, 2008). Drip irrigation is one of the most water use efficiency method of irrigation. Water losses from this mode of application are minimal. For instance, Surface runoff is often characterized with excessive application of water causing saturation of the soil and spillover of the excess. However, drip irrigation system mode of water delivery is slowly that could not cause surface runoff and thus loses due to runoff in this study were deemed negligible. The experiment used the drip irrigation system which does not lose excess amount of water as compared to other forms of irrigation. Farmers are also not expected to over irrigate hence cases of percolation below the root zone was minimum, and therefore, this study made an assumption that deep percolation below the root zone was not significant.

As such, this study sought to determine the best drip irrigation schedule that can ensure optimization in use of water as a productive resource. Different irrigation schedules were found to have a significant influence on growth and yield of cabbage. Time to maturity, number of cabbage heads per hectare, marketable yields per hectare and net revenue obtained per hectare were used as parameters for estimating the response of cabbage to varying irrigation schedules.

Time to maturity was observed to increase as the available soil moisture reduced. Cabbages grown under S1 took the shortest time to mature (9 weeks), followed by those in S2 (11 weeks) while those under S3 and S4 took the longest time to mature (13 to 15 weeks). On average, the cabbage cultivars investigated achieved maturity by the twelfth week. This finding was similar to that by Wen (2013) who reported a maturity period of 85 days (12 weeks) for cabbage. This is despite the two sites having different soil types and climatic conditions. The latter experiment was conducted in the silt loam soils and subtropical climate that is that experiences heavy precipitation. Moreover the cabbage cultivar (Autumn Queen) used was different from the ones used in the current study. A study by Nyatuame *et al.,* (2013) ascribed the delayed maturity under water stress to the tendency of crops to redirect the available water and energy towards survival rather than to production. The finding also corroborate the findings by Averbeke & Netshithuthuni (2010) who observed that performing irrigation twice a week would optimize early leaf development, maturation and the overall yield.

5.5 Cabbage Stand Count and Marketable Yields

There were no significant variations in cabbage stand counts and number of marketable cabbage heads per treatment between the irrigated treatments S1, S2 and S3. However, the rainfed treatment produced significantly lower number of marketable cabbage heads per unit area compared to the three irrigated treatments. Marketable cabbage heads here refer to those that had achieved physiological maturity (score 3 in table 3.1) as described by Rizzolo and Zerbini (2012) and were free from the common disorders (head split and tip burn). The cabbage stand count was observed to decrease as the irrigation frequency decreased from twice per week to once per week, then to once per fortnight to rainfed treatment. This trend was attributed to the water stress induced by reduced irrigation frequency. These findings are in coherence with those of Xu & Leskovar (2014) who revealed that yield components diminished as the amount of irrigation water supplied reduced. These findings indicate that the number of cabbage heads per unit area can be significantly improved through supplemental irrigation where rainfall is not adequate.

The marketable yields as determined by the cabbage head weight were found to increase as irrigation frequency increased where S1 (irrigated twice per week) recorded the highest yield and S4 (rainfed) recorded the lowest yields. These findings were similar to those reported by Kadyampakeni (2013) who investigated the response of cabbages to irrigation and observed the highest yield where supplemental irrigation was done twice a week whereas the lowest yields were obtained where supplemental irrigation was done after every fortnight. Similar findings were also reported by Averbeke & Netshithuthuni (2010), Himanshu *et al.* (2012), Kumar & Sahu (2013), Mzini (2013) and Xu & Leskovar (2014). Despite the locational and varietal differences, all the cited studies reported a decrease in cabbage head weight and ultimately reduced yields with reduced frequency of irrigation water implying that adequate soil moisture is key in achieving optimum yields in cabbage.

In the current study, as it was also the case in the previous studies, increasing the frequency of irrigation was found to increase the yield of cabbage. Therefore, supplemental irrigation is vital for cabbage productivity where rainfall is sub-optimal. Averbeke & Netshithuthuni (2010) reported that optimum growth and yield can be achieved by maintaining a required water content of the top soil and that requires twice a week irrigation. A similar argument and support of irrigating cabbage twice a week was also given by Beshir (2017) in his estimation of crop water requirement, irrigation frequency and water use efficiency of cabbage production.

5.6 Production Cost of Drip Irrigated Cabbages

Without considering the cost of seed, the production cost of the three test cabbage cultivars would be similar. However, the production cost was similar for Gloria and Riana cabbage cultivars over the seasons but was significantly high for Triperio cultivar due to relatively higher cost of seed. The production cost also varied significantly across the four irrigation schedules depicting a diminishing trend from S1 down to S4. The similar production cost for the three cabbage cultivars was enabled by their similar agronomic performance, resilience to water stress, water use efficiency and profitability as reported by small-scale farmers. In addition, all the other agronomic practices except irrigation were carried out uniformly in all the experimental plots. The difference in production cost among the different irrigation schedules arose from different labor demand and varying amount of irrigation water supplied. The S1 had the highest production cost due to its higher water input and more man hours used to apply the irrigation as compared to the other schedules. These finding are similar to those of Himanshu *et al*. (2012) who reported that production cost of irrigated cabbage increased with the increase in irrigation frequency.

5.7 Profitability of Drip Irrigated Cabbages

The net revenue accruing after the sale of cabbages varied significantly between the irrigation schedules although there were no significant differences between the net revenue obtained from S2 and S3. The difference between these two treatments may have been neutralized by the relatively huge revenue differences between treatments S1 and S4. However, the net revenue was found to decrease as irrigation frequency decreased. This was attributed to reduced yields of cabbages as water stress increased. These differences are attributed to the variations in stand count for each variety, in relation to their production in the first season of production.

Due to variations in weather conditions among the two seasons, the crop evapotranspiration was higher in season two than in the previous season, hence causing water stress and subsequently reduced head development. These findings are in line with those by Kondo *et al.* (2014) who investigated the economic returns of two different cabbage cultivars produced under different levels of irrigation and observed an increase in net income as the amount of supplemental irrigation water was increased. This shows that use of supplemental irrigation improved the total revenue from cabbage production in both seasons. Since the three cultivars had similar agronomic potential and were subjected to similar agronomic practices, the net revenue from the three cabbage cultivars did not vary significantly over the seasons. However, in season I, revenue from Triperio was significantly different to that of Gloria cultivar. This change in revenue is attributed to the low stand count and marketable cabbage heads that were realized for Triperio in season I compared to the other cultivars.

5.8 Correlation between irrigation and yield parameters

Significant correlations were found between irrigation parameters and yield parameters assessed in both production seasons. Significant correlations were established between irrigation water and water use efficiency, maturity period, tip burn, cabbage splitting, stand count and yield for both seasons. Irrigation water positively correlated with cabbage head splitting, stand count, yield and net revenue. This indicate that an increase in the amount of irrigation water resulted to an increase in head splitting incident, cabbage stand count and consequently yield and net revenue. This is true because head splitting incidents occur due to over watering (irrigating) after the cabbage head has attained its physiological maturity. The cabbage stand count could also increase with an increase in the amount of irrigation water since water is key to establishment of vegetables especially cabbage heads and with improved stand count, the yield is likely to increase and eventually the net revenue.

These findings corroborate with the one by Masarirambi *et al.* (2011) who also indicated that cabbage head splitting is a disorder usually caused by heavy precipitation, over irrigating and delayed harvesting. A study conducted by Erken & Yildirim (2019) to assess the yield and quality components of cabbage under varying irrigation levels reported that yields increased proportionally with the amount of irrigation water applied. The findings indicate that yield increased from 73625 $kgha^{-1}$ to 80458 $kgha^{-1}$ when irrigation water was increased from 261 mm to 314.1 mm. These findings agree with the above Pearson correlation findings indicating that increase in irrigation water causes a positive increment in yield which then translates to revenue. However, irrigation water negatively correlated with water productivity and water use efficiency. This implies that an increase in irrigation water reduces water productivity and water use efficiency. This assertion is in agreement with that of Zwart & Bastiaanssen, (2004) who reported that optimum water productivity and water use efficiency can be achieved by reducing the amount if irrigation water. Though tip burn disorder of cabbage negatively correlated with irrigation water, it's more of a nutrient disorder than a watering disorder. Nonetheless, excessive irrigation is likely to cause leaching of essential elements from the soil thus depriving the crop of its nutrients and this can contribute to occurrence of tip burn (Stowe *et al.,* 2010).

Water use efficiency significantly and positively correlated with maturity period implying that the cabbages were able to achieve their physiological maturity early when water use efficiency was increased. Water use efficiency correlated negatively with cabbage splitting, stand count, yield and net revenue. In the early sections, the study revealed that water use efficiency increased with a decrease in the amount of irrigation water. This means that as water use efficiency is increased (by reducing irrigation water), cabbage splitting disorder associated with excess watering will reduce. Moreover, cabbage stand count, yield and net revenue will decrease as the crop is deprived of water. This findings are in line with that of Masarirambi *et al.* (2011) as well as Erken & Yildirim (2019). Tip burn revealed a negative and weak relationship with all the variables it was correlated with (cabbage splitting, stand count, yield and net revenue) because it's a nutrient related disorder (not factored in the above correlations) rather than a water disorder. Stand count positively correlated with yield and net revenue which implies that increase in cabbage stand count, which most likely increases the number of marketable cabbage heads will improve the yield and eventually the net revenue through economies of scale (Narinbaeva *et al.*, 2021).

CHAPER SIX

CONCLUSION AND RECCOMENDATIONS

6.1 Conclusions

a) The time to maturity, head count, head weight and ultimate yield were found to increase as irrigation frequency increased. Despite the higher water supply demands, production was high under treatments where irrigation water was supplied twice a week, compared to the other treatments. The control treatment recorded the least yield in both seasons. The study therefore concludes that adequate moisture is key in ensuring optimum growth and yield of cabbage.

b) The varietal effects were insignificant on productivity parameters in response to the drip irrigation schedules that were investigated. The study therefore concludes that the type of cabbage cultivar used, among the selected, does not influence different performance in terms of growth and yielding.

c) Results indicated that water productivity and water use efficiency increased with decrease in the amount of irrigation water applied. This implies that water productivity and water use efficiency was highest under control treatment but low water availability resulted in dismal yields. The study therefore concludes that high water productivity and water use efficiency can still be achieved under economic use of available irrigation water.

d) On economic return on investment, the net revenues were found to increase as irrigation frequency increased. Despite the higher investment cost and relatively higher cost of production involved in where supplemental irrigation was applied twice a week (S1), its productivity and profitability were higher compared with other irrigation schedules. The study therefore concludes that optimum economic returns are feasible if the crop water and nutrient requirements are met efficiently. Moreover, vegetable farming can be more lucrative if producers target the dry season period of the year, if the above drip irrigation schedule is adopted for watering the crop.

6.2 Recommendations

a) From these statistics, the current study recommends that cabbage farmers in *humic nitisols* of Embu County and other areas with similar agro-ecological conditions should adopt the drip irrigation regime that is performed twice a week to maximize on the output and eventually revenue from their investment. This is supported by the findings from the Pearson correlation which indicated that there is a strong and positive correlation between the amount of irrigation and growth and yield parameters (stand count and yield).

b) Cabbage farmers may select any of the three cabbage varieties or any other with similar attributes and putting into consideration other production factors including the cost of seed, other agronomic variations, customer preference, and marketability. This is because, there were no significant differences on growth parameters evaluated among the cabbage cultivars. The time taken to attain physiological maturity, stand count and yield were not significantly different.

c) The study recommends that farmers should adopt the drip irrigation regime where water is supplied twice a week to reap from increased yields and improved revenues despite having a low water use efficiency and water productivity among the irrigation schedules and cabbage varieties.

d) This study recommends irrigation schedule (S1) for adoption by cabbage farmers under *humic nitisols* in Embu County and other areas with similar conditions in order to maximize on net revenue. In terms of cost, farmers should opt for Riana and Gloria cultivars in order to minimize on production cost. This is because, at the time of this study, Riana and Gloria cultivars had a similar cost of seeds ($35 per 100g sachet) while the cost of Triperio was slightly higher ($41 per 100g sachet). This difference in cost presents an economic burden considering that the net revenue from the three cultivars were not significantly different. The varietal effects were insignificant on both productivity and profitability in response to the drip irrigation schedules that were investigated. Cabbage farmers may therefore select any of the three or any other preferred variety since their revenue was not significantly different.

6.3 Further Research

This study focused on selected cabbage cultivars which compose a tiny proportion of the cabbage cultivars grown by farmers in Embu County. As such, there still remains a vast research gap for cultivars in order to have holistic information in regards to efficient resource use (water in this study) in attempts to cope with the current climate change effects of availability of the resources. This study therefore recommends:

a) Conduction similar studies using other cabbage varieties grown in the area at different water regimes

b) Conducting similar studies to test the effect of different irrigation methods of the growth and yield of cabbage

c) Determination of gross margins for other cabbage varieties grown under varying irrigation methods and different water regimes

d) Comparing the growth, yield and profitability of cabbage with other vegetables commonly grown in the area

e) Evaluate the effect of varying fertility levels on the growth and yield of cabbage in Embu County and related agroecological regions

REFERENCES

Abdullahi, I. O., & Abdulkareem, S. (2010). Bacteriological quality of some ready to eat vegetables as retailed and consumed in Sabon-Gari, Zaria, Nigeria. *Bayero Journal of Pure and Applied Sciences*, 3(1).

Adeniran, K. A., Amodu, M. F., Amodu, M. O., & Adeniji, F. A. (2010). Water requirements of some selected crops in Kampe dam irrigation project. *Australian Journal of Agricultural Engineering*, *1*(4), 119-125.

Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2016). Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment*, *543*, 295-306.

Ahmadi, S. H., Mosallaeepour, E., Kamgar-Haghighi, A. A., & Sepaskhah, A. R. (2015). Modeling Maize Yield and Soil Water Content with AquaCrop under Full and Deficit Irrigation Managements. *Water Resources Management*, 29(8), 2837–2853.

Ali, M. & Mubarak, S. (2017). "Effective rainfall calculation methods for field crops: an overview, analysis and new formulation," *Asian Research Journal of Agriculture*, 7(1), 1–12.

Ali, M. H. & Talukder, M. S. U. (2008). Increasing water productivity in crop production-A synthesis, *Agricultural Water Management*, 95(11), 1201–1213.

Al-Said, F. A., Ashfaq, M., Al-Barhi, M., Hanjra, M. A., & Khan, I. A. (2012). Water productivity of vegetables under modern irrigation methods in Oman. *Irrigation and Drainage*, 61(4), 477–489.

Aluku, H., Komakech, H. C., van Griensven, A., Mahoo, H., & Eisenreich, S. (2021). Seasonal profitability of soil and water conservation techniques in semi-arid agro-ecological zones of Makanya catchment, Tanzania. *Agricultural Water Management*, *243*, 106493.

Averbeke, W. V. and Netshithuthuni, C. (2010). Effect of irrigation scheduling on leaf yield of non-heading Chinese cabbage (Brassica rapaL. subsp.chinensis), *South African Journal of Plant and Soil*, 27(4), 322–327.

Bastiaanssen, W. G. M., Noordman, E. J. M., Pelgrum, H., Davids, G., Thoreson, B. P., & Allen, R. G. (2005). SEBAL model with remotely sensed data to improve water-resources management under actual field conditions. *Journal of irrigation and drainage engineering*, *131*(1), 85-93.

Begna, F., & Damtew, T. (2015). Evaluation of four botanical insecticides against Diamondback Moth, *Plutella Xylostella* L. (*Lepidoptera Plutellidae*) on head cabbage in the central rift valley of Ethiopia. *Spanish Journal of Agricultural Research*, 4, 97-105.

Beshir, S. (2017). Review on estimation of crop water requirement, irrigation frequency and water use efficiency of cabbage production. *Journal of Geoscience and Environment Protection*, *5*(07), 59.

Broadbent, A. M., Coutts, A. M., Tapper, N. J., & Demuzere, M. (2018). The cooling effect of irrigation on urban microclimate during heatwave conditions. *Urban climate*, *23*, 309-329.

Brouwer, C., Prins, K., Kay, M., & Heibloem, M. (1988). Irrigation water management: irrigation methods. *Training manual*, *9*(5), 5-7.

Caunii, A., Pribac, G., & Butnariu, M. (2011). Operational Marketing of Vegetal Products having Antioxidant Biocomponents. Studia Universitatis" Vasile Goldis" Arad. *Seria Stiintele Vietii (Life Sciences Series)*, 21, 557

Chek A. L., (1999). Laboratory methods of soil analysis: Determination of Na, K, Ca, Mg, P and Mn in a hydrochloric acid-sulphuric acid extract (Mehlich double acid method). Kenya Agricultural Research Institute: National Agricultural Research Laboratories, Nairobi.

Chikodzi, D., Zinhiva, H., Simba, F. M., & Murwendo, T. (2013). Reclassification of agro-ecological zones in Zimbabwe-the rationale, methods and expected benefits: The case of Masvingo province. *Journal of Sustainable Development in Africa*, *15*(1), 104-116.

Cohen, M. J., & Garrett, J. L. (2010). The food price crisis and urban food (in) security. *Environment and Urbanization.* 22, 467-482.

Çolak, Y. B., Yazar, A., Çolak, İ., Akça, H., & Duraktekin, G. (2015). Evaluation of Crop Water Stress Index (CWSI) for Eggplant under Varying Irrigation Regimes Using Surface and Subsurface Drip Systems. *Agriculture and Agricultural Science Procedia,* 4, 372–382.

Corbeels, M., De Graaff, J., Ndah, T. H., Penot, E., Baudron, F., Naudin, K. & Rusinamhodzi, L. (2014). Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems & Environment,* 187, 155-170.

Daccache, A., Knox, J. W., Weatherhead, E. K., Daneshkhah, A., & Hess, T. M. (2015). Implementing precision irrigation in a humid climate - Recent experiences and on-going challenges. *Agricultural Water Management,* 147(January), 135–143.

Dağdelen, N., Başal, H., Yılmaz, E., Gürbüz, T., & Akcay, S. (2009). Different drip irrigation regimes affect cotton yield, water use efficiency and fiber quality in western Turkey. *Agricultural Water Management,* 96, 111-120.

De Pascale, S., Costa, L. D., Vallone, S., Barbieri, G., & Maggio, A. (2011). Increasing water use efficiency in vegetable crop production: From plant to irrigation systems efficiency. *HortTechnology,* 21, 301–308.

De Zeeuw, H., Van Veenhuizen, R., & Dubbeling, M. (2011). The role of urban agriculture in building resilient cities in developing countries. *The Journal of Agricultural Science*, 149, 153-163.

Dukes, M. D., Zotarelli, L., & Morgan, K. T. (2010). Use of irrigation technologies for vegetable crops in Florida. *HortTechnology,* 20(1), 133–142.

Eckert, D., & Sims, J. T. (1995). Recommended soil pH and lime requirement tests. Recommended soil testing procedures for the northeastern United States. Northeast Regional Bulletin, *493*, 11-16.

Erken, O., & Yildirim, M. (2019). Yield and Quality Compounds of White Cabbage (Brassica oleracea L. cv. Capitata) under Different Irrigation Levels. *Journal of Agricultural Science and Technology*, *21*(5), 1341-1352.

Esteve, P., Fronzek, S., Downing, T. E., Blanco-Gutiérrez, I., Varela-Ortega, C., & Bharwani, S. (2014). How can irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain. *Regional Environmental Change*, 16(1), 59–70.

Fan, Y., Wang, C., & Nan, Z. (2014). Comparative evaluation of crop water use efficiency, economic analysis and net household profit simulation in arid Northwest China. *Agricultural Water Management*, 146, 335–345.

Fanadzo, M., Chiduza, C., & Mnkeni, P. N. S. (2010a). Overview of smallholder irrigation schemes in South Africa: Relationship between farmer crop management practices and performance. *African Journal of Agricultural Research Special Review,* 5(25), 3514–3523.

Fanadzo, M., Chiduza, C., Mnkeni, P. N. S., van der Stoep, I., & Stevens, J. (2010b). Crop production management practices as a cause for low water productivity at Zanyokwe Irrigation Scheme. *Water SA*, 36(1), 27–36.

Faurès, J.-M., Hoogeveen, J., & Bruinsma, J. (2002). The Fao Irrigated Area Forecast for 2030. FAO, Rome, Italy, 1–14. Retrieved from http://www.fao.org/tempref/agl/AGLW/docs/fauresetalagadir.pdf

Fentahun Adametie, T. (2020). Effects of Conservation Agriculture and Irrigation Systems on Crop and Water productivity in The Ethiopian Highlands (*Doctoral dissertation*, Bahir Dar University).

Gateri, M. W. (2015). Domestic rainwater harvesting: a case study in Embu County, Kenya. *Africa Journal of Physical Sciences ISSN: 2313-3317*, *2*(1).

Geerts, S., & Raes, D. (2009). Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural water management*, *96*(9), 1275-1284.

Ghosh, S., Lockwood, P., Hulugalle, N., Daniel, H., Kristiansen, P., & Dodd, K. (2010). Changes in properties of sodic Australian Vertisols with application of organic waste products. *Soil Science Society of America Journal*, *74*(1), 153-160.

Government of Kenya (2010) National Climate Change Response Strategy. Available at: http:// cdkn.org/wp-content/uploads/2012/04/National-Climate-Change-Response-Strategy_April2010.pdf. Accessed 10 December 2016.

Greaves, G. E., & Wang, Y. M. (2017). Identifying irrigation strategies for improved agricultural water productivity in irrigated maize production through crop simulation modelling. *Sustainability*, *9*(4), 630.

Grewal, H. S., Maheshwari, B., & Parks, S. E. (2011). Water and nutrient use efficiency of a low-cost hydroponic greenhouse for a cucumber crop: An Australian case study. *Agricultural Water Management*, *98*(5), 841-846.

Gummadi, S., Kadiyala, M. D. M., Rao, K. P. C., Athanasiadis, I., Mulwa, R., Kilavi, M., ... & Amede, T. (2020). Simulating adaptation strategies to offset potential impacts of climate variability and change on maize yields in Embu County, Kenya. *PloS one*, *15*(11), e0241147.

Heinke, J., Lucht, W., Schaphoff, S., Kummu, M., Gerten, D., & Jägermeyr, J. (2015). Water savings potentials of irrigation systems: global simulation of processes and linkages. *Hydrology and Earth System Sciences,* 19(7), 3073–3091.

Himanshu, S. K., Kumar, S., Kumar, D. and Mokhtar, A. (2012) "Effects of lateral spacing and irrigation scheduling on drip irrigated cabbage (Brassica oleracea) in a semi-arid region of India," *Research Journal of Engineering Sciences* 2278(6), 9472.

Hofstrand, D. (2009). Understanding profitability. *Ag Decisions Makers*, *2*, C3-24.

http://www.fao.org/fileadmin/user_upload/agwa/docs/bari2017/Session1/Productivity_introduction_I.pdf

https://www.jica.go.jp/project/english/kenya/015/materials/c8h0vm0000f7o8cj-att/materials_21.pdf

https://knoema.com/atlas/sources/KN

https://waterfund.go.ke/watersource/Downloads/001.%20Irrigation%20Potential%20and%20Achievements.pdf

Inthichack, P., Nishimura, Y., & Fukumoto, Y. (2012). Effect of potassium sources and rates on plant growth, mineral absorption, and the incidence of tip burn in cabbage, celery, and lettuce. *Horticulture, Environment, and Biotechnology*, *53*(2), 135-142.

Irmak, S., Odhiambo, L. O., Kranz, W. L., & Eisenhauer, D. E. (2011). Irrigation efficiency, uniformity and crop water use efficiency. *Hydrology and Earth System Sciences, 17(5), 1-14.*

Jabiol, B., Zanella, A., Ponge, J. F., Sartori, G., Englisch, M., Van Delft, B., & Le Bayon, R. C. (2013). A proposal for including humus forms in the World Reference Base for Soil Resources (WRB-FAO). *Geoderma,* 192, 286-294.

Jiang, Y., Xu, X., Huang, Q., Huo, Z., & Huang, G. (2015). Assessment of irrigation performance and water productivity in irrigated areas of the middle Heihe River basin using a distributed agro-hydrological model. *Agricultural Water Management*, 147, 67–81.

Kadiresan, K., & Khanal, P. R. (2018). Rethinking irrigation for global food security. *Irrigation and drainage*, *67*(1), 8-11.

Kadyampakeni, D. M. (2013). "Comparative response of cabbage to irrigation in Southern Malawi," *Journal of Agricultural Science*, vol. 5, no. 8, p. 1.

Kanda, E. K., & Lutta, V. O. (2022). The status and challenges of a modern irrigation system in Kenya: A systematic review. *Irrigation and Drainage*.

Kang, Y., Khan, S., & Ma, X. (2009). Climate change impacts on crop yield, crop water productivity and food security–A review. *Progress in natural Science*, 19, 1665-1674.

Kebede, S. W., & Bokelmann, W. (2017). African indigenous vegetables and their production practices: evidence from the HORTINLEA survey in Kenya. *Agrotechnology*, *6*(170), 2.

Killebrew, K., & Wolff, H. (2010). Environmental Impacts of Agriculture technologies. *Evans School Policy Analysis and Research*, (65), 1–18.

Kisaka, M. O., Mucheru-Muna, M., Ngetich, F. K., Mugwe, J. N., Mugendi, D., & Mairura, F. (2015). Rainfall Variability, Drought Characterization, and Efficacy of Rainfall Data Reconstruction: Case of Eastern Kenya. *Advances in Meteorology*, 2015, 1–16.

Kisaka, O., Mucheru-Muna, M., Ngetich, F. K., Mugwe, J., Mugendi, D., & Mairura, F. (2013). Seasonal rainfall variability and aptness of Geographical-Information-Systems (GIS) interpolation techniques in the arid regions of Embu County, Kenya. *African Crop Science Conference Proceedings*, 11(2008), 883–893.

Kitalyi, A., Nyadzi, G., Lutkamu, M., Swai, R., & Gama, B. (2010). New climate, new agriculture: how Agroforestry contributes to meeting the challenges of Agricultural development in Tanzania. *Tanzania Journal of Agricultural Sciences*, 10(1).

Koksal, E. S., Tasan, M., Artik, C., & Gowda, P. (2017). Evaluation of financial efficiency of drip-irrigation of red pepper based on evapotranspiration calculated using an iterative soil water-budget approach. *Scientia Horticulturae*, 226(March), 398–405.

Kondo, E., Asare, D. K. & Larteh, I. T., (2014). “Economic analysis of two cabbage cultivars produced at different levels of applied water,” *International Journal of Development and Sustainability*, 3(10), 2006–2013.

Korir, J. K., Affognon, H. D., Ritho, C. N., Kingori, W. S., Irungu, P., Mohamed, S. A., & Ekesi, S. (2015). Grower adoption of an integrated pest management package for management of mango-infesting fruit flies (Diptera: Tephritidae) in Embu, Kenya. *International Journal of Tropical Insect Science*, *35*(2), 80-89.

Kumar, P. and Sahu, R. L. (2013). “Effect of irrigation and fertigation levels on cabbage,” *An Asian Journal of Soil Science*, 8(2), 270–274.

Lenné, J. M., & Ward, A. F. (2010). Improving the efficiency of domestic vegetable East Africa Constraints and opportunities. *Outlook on Agriculture* 39, 31–40.

Liu, G., & Hanlon, E. (2012). Soil pH range for optimum commercial vegetable production. *Asian Journal of Soil Science*, 12(7), 20–24

Liu, J., & Yang, H. (2010). Spatially explicit assessment of global consumptive water uses in cropland: Green and blue water. *Journal of Hydrology*, 384, 187–197.

Mairura, F. S., Mugendi, D. N., Mwanje, J. I., Ramisch, J. J., Mbugua, P. K., & Chianu, J. N. (2007). Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya. *Geoderma*, *139*(1-2), 134-143.

Manchali, S., Chidambara Murthy, K. N., & Patil, B. S. (2012). Crucial facts about health benefits of popular cruciferous vegetables. *Journal of Functional Foods*, 4(1), 94–

Manderscheid, R., Dier, M., Erbs, M., Sickora, J., & Weigel, H. J. (2018). Nitrogen supply–A determinant in water use efficiency of winter wheat grown under free air CO2 enrichment. *Agricultural water management*, 210, 70-77.

Masarirambi, M. T., Oseni, T. O., Shongwe, V. D., & Mhazo, N. (2011). Physiological disorders of Brassicas/Cole crops found in Swaziland: A review. *African Journal of Plant Science*, *5*(1), 8-14.

Mbava, N., Mutema, M., Zengeni, R., Shimelis, H., & Chaplot, V. (2020). Factors affecting crop water use efficiency: A worldwide meta-analysis. *Agricultural Water Management*, *228*, 105878.

McCord, P. F., Cox, M., Schmitt-Harsh, M., & Evans, T. (2015). Crop diversification as a smallholder livelihood strategy within semi-arid agricultural systems near Mount Kenya. *Land Use Policy*, 42, 738-750.

McKeown, A. W., Westerveld, S. M., & Bakker, C. J. (2010). Nitrogen and water requirements of fertigated cabbage in Ontario. *Canadian Journal of Plant Science*, 90(1), 101–109

Miruri, R., & Wanjohi, J. (2017). Determinants of performance of irrigation projects: Case of Nthawa irrigation project of Mbeere North Sub-county, Embu County, Kenya. *International Academic Journal of Information Sciences and Project Management*, 2, 447-463.

Muhajir, Wilson, J., Grantham, H. S., Mongdong, M., Agostini, V. N., Hidayat, N., Beck, M. W. (2012). A comparison of zoning analyses to inform the planning of a marine protected area network in Raja Ampat, Indonesia. *Marine Policy*, 38, 184–194.

Muriithi, B. W., & Matz, J. A. (2015). Welfare effects of vegetable commercialization: Evidence from smallholder producers in Kenya. *Food Policy*, 50, 80-91.

Muyanga, M., & Jayne, T. S. (2014). Effects of rising rural population density on smallholder agriculture in Kenya. *Food Policy*, 48, 98-113.

Mzini, L. L. (2013). "Effects of grey water irrigation on vegetable crops and soil," M. S. %esis, University of Cape Town, Cape Town, South Africa.

Nakayama, F. S., & Bucks, D. A. (Eds.). (2012). *Trickle irrigation for crop production: design, operation and management*. Elsevier.

Narinbaeva, G., Menglikulov, B., Siddikov, Z., Bustonov, K., & Davlatov, S. (2021). Application of innovative technologies in agriculture of Uzbekistan. In *E3S Web of Conferences* (Vol. 284, p. 02009). EDP Sciences.

Ndhleve, S., Nakin, M. D. V., & Longo-Mbenza, B. (2017). Impacts of supplemental irrigation as a climate change adaptation strategy for maize production: A case of the Eastern Cape Province of South Africa. *Water SA*, 43(2), 222–228.

Ndungu, S. K., & Macharia, I. (2013). Analysis of profitability of organic vegetable production system in Kiambu and Kajiado counties of Kenya. *In African Crop Science Conference Proceedings* 11, 11, 605–611.

Njenga, PM (2015) Agricultural export supply response to price and non-price variables: a case of horticultural sub-sector in Kenya. Kenyatta University.

Njiraini, G. W., & Guthiga, P. M. (2013). Are small-scale irrigators water use efficient? Evidence from Lake Naivasha Basin, Kenya. *Environmental management, 52*(5), 1192-1201.

Nyambo, P., & Wakindiki, I. I. C. (2015). Water footprint of growing vegetables in selected smallholder irrigation schemes in South Africa. *Water SA*, 41(4), 571–578.

Nyatuame, M., Ampraw, F., Owusu-Gyimah, V. and Ibrahim, B. M. (2013). "Irrigation scheduling and water use efficiency on cabbage yield," *International Journal of Agricultural Research*, 3, 29–35.

Ochieng, J., Kirimi, L., & Mathenge, M. (2016). Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. NJAS - *Wageningen Journal of Life Sciences,* 77, 71–78.

Olayide, O. E., Tetteh, I. K., & Popoola, L. (2016). Differential impacts of rainfall and irrigation on agricultural production in Nigeria: Any lessons for climate-smart agriculture? *Agricultural Water Management*, 178, 30–36.

O'Leary, N., Ahrend, A., McDonaeh, A., O'Brien, B., & Shalloo, L. (2018). A partial budgeting tool to assess investments in Precision Dairy Technologies. In *Sustainable meat and milk production from grasslands. Proceedings of the 27th General Meeting of the European Grassland Federation, Cork, Ireland, 17-21 June 2018* (pp. 810-812). Teagasc, Animal & Grassland Research and Innovation Centre.

Olle, M., & Williams, I. H. (2017). Physiological disorders in tomato and some methods to avoid them. *The Journal of Horticultural Science and Biotechnology,* 92(3), 223-230.

Olmstead, S. M. (2010). The economics of managing scarce water resources. Review of *Environmental Economics and Policy*, 4(2), 179–198.

Onyari, C. N., Kibe, A. M., & Mwonga, S. (2015). Growth parameters of DK8031 maize variety as affected by varying irrigation and nitrogen fertilizer rates in Embu County, Kenya.

Osondu, C. K., Nwadike, F. C., Ijioma, J. C., Udah, S. C., & Ugboaja, C. I. (2014). Marketing performance of salad vegetables: The case of cabbage marketing in Abia State, Nigeria. *International Journal of Agricultural Science,* 4(3), 151–162.

Paranhos, L. G., Barrett, C. E., Zotarelli, L., Darnell, R., Migliaccio, K., & Borisova, T. (2016). Planting date and in-row plant spacing effects on growth and yield of cabbage under plastic mulch. *Scientia Horticulturae,* 202, 49–56.

Pardossi, A., & Incrocci, L. (2011). Traditional and new approaches to irrigation scheduling in vegetable crops. *HortTechnology*, 21, 309-313.

Pereira, L. S., Cordery, I., & Iacovides, I. (2012). Improved indicators of water use performance and productivity for sustainable water conservation and saving. *Agricultural water management*, *108*, 39-51.

Perry, C., Steduto, P., Allen, R. G., & Burt, C. M. (2009). Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities. *Agricultural water management*, *96*(11), 1517-1524.

Plag, I. (2020). Productivity. *The handbook of English linguistics*, 483-499.

Rapsomanikis, G (2014) The economic lives of smallholder farmers; An analysis based on household surveys. FAO Rome. Available at: http://www.fao.org/3/a-i5251e.pdf. Accessed 5 Dec 2016.

Reed, M. S., Stringer, L. C., Dougill, A. J., Perkins, J. S., Atlhopheng, J. R., Mulale, K., & Favretto, N. (2015). Reorienting land degradation towards sustainable land management: Linking sustainable livelihoods with ecosystem services in rangeland systems. *Journal of Environmental Management,* 151, 472–485.

Rizzolo, A., & Zerbini, P. E. (2012). Harvest maturity indicators - Introduction. Stewart Postharvest *Review,* 8(1), 1–3.

Roopashree, M., Rajkumara, S., Amrutha, T. G., Nalina, C. N., Shilpa, H. D., & Varshitha, V. (2020). Growth and yield response of Bt cotton (Gossypium hirsutum L.) to surface and subsurface drip irrigation. *Journal of Pharmacognosy and Phytochemistry*, *9*(5), 1004-1008.

Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J., & Schaphoff, S. (2008). Agricultural green and blue water consumption and its influence on the global water system. *Water Resources Research*, *44*(9).

Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J., & Schaphoff, S. (2008). Agricultural green and blue water consumption and its influence on the global water system. *Water Resources Research*, *44*(9).

Ryder, E. (2011). World vegetable industry: production, breeding, trends. *Hortic Rev*, 38, 299.

Seidel, S. J., Werisch, S., Schütze, N., & Laber, H. (2017). Impact of irrigation on plant growth and development of white cabbage. *Agricultural water management*, *187*, 99-111.

Sharanappa, J., Shekar, B. G., & Sridhara, S. (2000). Water use efficiency and yield of cabbage as influenced by drip and furrow methods of irrigation. *Indian Agriculturist*, *44*(3/4), 153-155.

Sharma, V., Irmak, S., Djaman, K., & Sharma, V. (2016). Large-scale spatial and temporal variability in evapotranspiration, crop water-use efficiency, and evapotranspiration water-use efficiency of irrigated and rainfed maize and soybean. *Journal of Irrigation and Drainage Engineering*, *142*(3), 04015063.

Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. (2010). Groundwater use for irrigation - A global inventory. *Hydrology and Earth System Sciences*, 14(10), 1863–1880.

Singh, A. K., Rahman, A., Sharma, S. P., Upadhyaya, A., & Sikka, A. K. (2009). Small holders' irrigation - Problems and options. *Water Resources Management*, 23(2), 289–302.

Singh, M., Singh, P., Singh, S., Saini, R. K., & Angadi, S. V. (2021). A global meta-analysis of yield and water productivity responses of vegetables to deficit irrigation. *Scientific reports*, *11*(1), 1-13.

Singh**,** S., Singh, N., & Pandey, Y. (2020). Water Productivity of Vegetables Crop under Temperate Condition of Kashmir Valley. *International Journal of Current Microbiology and Applied Science*, *9*(7), 3152-3168.

Singh, V., & Nautiyal, N. (2017). Water Productivity: A Perspective on Enhancing Ecosystem Functioning and Harvesting Opportunities. *Productivity*, *57*(4).

Stöber, S., Moraza, C., Zahl, L., & Kagai, E. (2018). Low-Tech irrigation strategies for smallholder vegetable farmers in Kenya. In *Rainwater-Smart Agriculture in Arid and Semi-Arid Areas* (pp. 215-233). Springer, Cham.

Stowe, D. C., Lamhamedi, M. S., Carles, S., Fecteau, B., Margolis, H. A., Renaud, M., & Bernier, P. Y. (2010). Managing irrigation to reduce nutrient leaching in containerized white spruce seedling production. *New Forests*, *40*(2), 185-204.

Šturm, M., Kacjan-Maršić, N., Zupanc, V., Bračič-Železnik, B., Lojen, S., & Pintar, M. (2010). Effect of different fertilisation and irrigation practices on yield, nitrogen uptake and fertiliser use efficiency of white cabbage (*Brassica oleracea* var. *capitata* L.). *Scientia Horticulturae,* 125(2), 103–109.

Tang, Y., Sun, X., Hu, C., Tan, Q., & Zhao, X. (2013). Genotypic differences in nitrate uptake, translocation and assimilation of two Chinese cabbage cultivars [Brassica campestris L. ssp. Chinensis (L.)]. *Plant Physiology and Biochemistry*, 70, 14-20.

Tilahun, H., Teklu, E., Michael, M., Fitsum, H., & Awulachew, S. B. (2011). Comparative performance of irrigated and rainfed agriculture in Ethiopia. *World Applied Sciences Journal*, 14(2), 235–244.

Tiwari, S. C., Kumawat, N., Bangar, K. S., Sharma, R. K., Kaledhonkar, M. J., & Meena, B. L. (2020). Yield and Water Productivity of Cabbage on Sodic Vertisols as Influenced by Drip Application Rate and Irrigation Schedule. *Journal of Soil Salinity and Water Quality*, *12*(2), 271-276.

Tongeren, W. B. (1937). Gravimetric analysis: A laboratory manual woth special reference to the analysis of natural minerals and rocks. *D. B. Centen's uitgevers-maatschappij n.v 1, 146-213*

Waddington, S. R., Li, X., Dixon, J., Hyman, G., & De Vicente, M. C. (2010). Getting the focus right: production constraints for six major food crops in Asian and African farming systems. *Food Security*, 2, 27-48.

Ward, F. A. (2014). Economic impacts on irrigated agriculture of water conservation programs in drought. *Journal of Hydrology*, 508, 114–127.

Wen, F., Zhang, B., Liu, X., Luo, Z., Zhao, B., Wang, C. & Li, M. (2013). A new Chinese cabbage F1 hybrid-'Zhenlyu 80'. *China Vegetables*, (6), 93-95.

Wheeler, T. A., Anderson, M. G., Russell, S. A., Woodward, J. E., & Mullinix, B. G. (2015). Application Pressure and Carrier Volume Affects the Concentration of Azoxystrobin on Peanut Foliage and in Soil. *Peanut Science,* 42(2), 128–137.

Woltering, L., Ibrahim, A., Pasternak, D., & Ndjeunga, J. (2011). The economics of low pressure drip irrigation and hand watering for vegetable production in the Sahel. *Agricultural Water Management*, *99*(1), 67-73.

World Bank (2016) World Bank Open Data. World Development Indicators—Data Kenya [Online]. Available at: http://data.worldbank.org/. Accessed 6 July 2016.

Xie, H., You, L., Wielgosz, B., & Ringler, C. (2014). Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. *Agricultural Water Management*, 131, 183–193.

Xu, C. and Leskovar, D. I. (2014). "Growth, physiology and yield responses of cabbage to deficit irrigation," *Horticultural Science*, 41(3), 138–146.

Yanglem, S. D., & Tumbare, A. D. (2014). Influence of irrigation regimes and fertigation levels on yield and physiological parameters in cauliflower. *The Bioscan*, 9(2), 589–594.

Yi, L., Shenjiao, Y., Shiqing, L., Xinping, C., & Fang, C. (2010). Growth and development of maize (Zea mays L.) in response to different field water management practices: Resource capture and use efficiency. *Agricultural and Forest Meteorology*, *150*(4), 606-613.

Yu, L., Xie, H., Wood-Sichra, U., Guo, Z., & Wang, L. (2014). Irrigation potential and investment return in Kenya. *Food Policy*, 47, 34–45

Zwart, S. J., & Bastiaanssen, W. G. (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural water management*, *69*(2), 115-133.