EVALUATION OF THE EFFECT OF COMBINED USE OF ORGANIC AND INORGANIC FERTILIZERS ON BULB ONION (*Allium cepa* L.) YIELDS AND FORECAST POTENTIAL ONION YIELDS UNDER CLIMATE CHANGE SCENARIOS IN WEST UGENYA SUB-COUNTY, KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT ROR THE REQUIREMENT OF THE AWARD OF A MASTER OF SCIENCE DEGREE IN LAND AND WATER MANAGEMENT

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FACULTY OF AGRICULTURE
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January 2018

DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other academic institution.

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DEDICATION

I dedicate this thesis to my dear parents, Mr. and Mrs. Mbindah, my sisters: Diana, Fiona and Ashley, my cousin Maurice, and my dear uncle Pancras and Aunty Mary for unconditionally supporting me during my field study.

ACKNOWLEDGMENT

I first give thanks to the almighty God for giving me good health and strength to undertake this thesis project to completion. I am also very grateful to my university supervisors, Dr. George N. Karuku and Prof. Charles K. K Gachene of the University of Nairobi, Department of Land Resource Management and Agricultural Technology (LARMAT) for their invaluable advice, support and guidance throughout this study period. Their consistent dedication and encouragement ensured this project was a success. I also acknowledge the entire laboratory staff of the University of Nairobi, Upper Kabete Campus and Kenya Agricultural and Livestock Research Organization (KALRO), Nairobi, my sincere appreciation for the technical support in analysis of my soil samples. And to my relatives, classmates, friends and all those who helped me in one way or another, may this thesis report be a show of gratitude to you all.

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ABBREVIATIONS AND ACRONYMS

AFFA – Agriculture, Fisheries and Food Authority

ANOVA – Analysis of Variance

ASALs – Arid and Semi-Arid Lands

CAN – Calcium Ammonium Nitrate

CEC – Cation Exchange Capacity

CGIAR - Consultative Group for International Agricultural Research

CSA – Climate Smart Agriculture

FAO – Food and Agriculture Organization of the United Nations

FAOSTAT - Food and Agriculture Organization Corporate Statistical Database

GCM – Global Circulation Model

GDP – Gross Domestic Product

IPCC – International Panel on Climate Change

KALRO - Kenya Agricultural and Livestock Research Organization

KIPPRA - Kenya Institute for Public Policy Research and Analysis

KNBS – Kenya National Bureau of Statistics

masl – Meters above sea level

MOA – Ministry of Agriculture

Mg – Mega grams

NOAA – National Oceanic and Atmospheric Administration

ppm – Parts per million

RCP – Representative Concentration Pathway

RMSE – Residual Mean Sum of Error

TSP – Triple Super Phosphate

USAID – United States Agency for International Development

USDA - United States Department of Agriculture

WHO – World Health Organization

WRB - World Reference Base for Soil Resources

ABSTRACT

Reduced crop yields in West Ugenya sub-county are attributable to poor soil fertility exacerbated by climate change. The combined use of organic and inorganic fertilizers is a potential solution to reduced yields and was thus evaluated against singular use of either organic or inorganic fertilizers on bulb onion yields in this study area. A randomized complete block design field experiment was carried out for two seasons during the 2015 and 2016 short and long rains. Four soil fertility treatments consisting of, namely: T_1 (5 Mg ha^{-1} cattle manure), T_2 (46 kg P ha^{-1} x 26 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), and T_4 (half T_1 x half T_2) were evaluated. Highest bulb yield in Mg ha^{-1} and largest bulb diameter of grade 1 quality (i.e. $\geq$ 5 cm bulb diameter) were recorded in T_4 compared to the other treatments in both seasons, indicating that onion yields could be significantly ($P \leq 0.05$) increased with combined use of 2.5 Mgha^{-1} cattle manure and 23 kg P ha^{-1} x 13 kg N ha^{-1} inorganic fertilizers in the study area. Projected climate change data for study area in the 2020 - 2039 period, derived from a global circulation model indicated that temperature will rise by 1.5^{o}C affecting predicted future onion yields modeled by AquaCrop model version 5.0. Predicted future yields would drop by between 4 and 10% in all treatments where the crop growth period will be reduced ($P \leq 0.05$) by an average of 15 days in all treatments compared to the baseline 1986 - 2005 period. Hence, combined use or organic and inorganic fertilizers can mitigate the declining soil fertility and increase onion yields in West Ugenya sub-county; however climate change will negatively affect future yields unless adaptive measures such as supplemental irrigation and mulching are implemented.

Keywords: AquaCrop, climate change, *Allium cepa*, cattle manure

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The bulb onion (*Allium cepa*) is an important spice for foods, soups, seasoning salads and stews. It is rich in vitamin E and has a myriad of therapeutic properties including the prevention of age-dependent changes in the blood vessels, loss of appetite, treatment of bacterial infections for example dysentery, management of ulcers, wounds, scars, asthma and also as an adjuvant therapy for diabetes (WHO, 1999). For optimal growth and development, bulb onions require temperature range of 12 – 25 ^{o}C and annual rainfall of 350 – 600 mm on well drained medium textured soils with a pH range of 6 – 7 (Muendo and Tschirley, 2004) to achieve optimum yield of 17 Mgha^{-1} (Jaetzold *et al*., 2009).

The rapidly declining soil fertility is the main constraint in a vast majority of Kenya's agricultural land; a major cause for the sluggish growth in food production by smallholder farmers in sub-Saharan Africa (Odendo *et al*., 2007). Combined use of organic and inorganic fertilizers is being advocated as a management option that can alleviate the diminishing soil health in sub-Saharan Africa (Sanginga and Woomer, 2009; Bationo *et al*., 2012, Vanlauwe *et al*., 2015; Ruganzu *et al*., 2015) and enhance and sustain agricultural productivity.

However, the vagaries of weather due to climate change is a threat to the already poor soils of sub Saharan Africa, which will further cause potential changes in soil fertility with respect to soil hydrology, soil temperature regime and organic matter supply from biomass (Brinkman and Sombroek, 1996) and decline in organic matter content. It has been documented that the Earth's average temperature has risen by about 0.6 ^{o}C during the 20th century (IPCC, 2007) attributed to increased carbon dioxide (CO_2) concentration in the atmosphere (and other greenhouse gases) which reached an alarming 400 ppmv in April 2013 according to Mauna Loa observatory Station in Hawaii (Monroe, 2013; NOAA, 2016). This means that activities that greatly depend on climate are facing uncertainties, particularly agriculture. Warmer temperatures may make many crops grow more quickly, but could also lead to floods and drought that again could lower yields, increase irrigation water requirements in areas that depended on rain-fed agriculture, cause delayed planting and harvesting due to shifting seasonal rainfall patterns and also increase pests and diseases (IPCC, 2007).

Higher atmospheric CO_2 concentrations in the humid tropics and monsoon climates, resulting into increased rainfall amounts and intensities would increase nutrient leaching rates in well-drained soils with high infiltration rates, leading to temporary flooding or water-saturation, hence reduced organic matter decomposition. This may lower the productivity of a significant part of most soils in Sub-Saharan Africa (Brinkman and Sombroek, 1996).

There is limited information on climate change is available for East Africa at country level or local scale (Herrero *et al*., 2010; Luedeling, 2011). Nonetheless, predictions by GCMs indicate that in the future Kenya will become wetter where by high rainfall events are projected to increase during the short and long rains, respectively. On the other hand, cropping might no longer be possible in the ASALs as a result of climate change with some evidence already being reported in Yatta Sub-County (Herrero *et al*., 2010; Chepkemoi *et al*., 2014).

In Siaya County for instance, rainfall unreliability and drought (Mango, 1999; and Herrero *et al*., 2010) have been noted to constraint agricultural production, and can be linked to effects of climate change and variability. Even so, numerous other challenges continue to contribute to lower crop productivity in Ugenya, especially for the economically viable onion crop. These include: continuous cropping on infertile soils, little use of recommended manures and/or fertilizer rates, poor soil management practices, and use of unimproved low yielding crop varieties (Jaetzold *et al*., 2009).

Traditionally, crop yield estimations have been based on empirical data but until recently, crop growth simulation models have been used to understand the effects of genotype, soil and management practices on crops, and further in the assessment of the impacts of climate variability and change on agriculture (Rinaldi *et al*., 2003; Rao and Wani, 2011). One such model relevant to this study is AquaCrop. It simulates attainable yields of the major herbaceous crops in rain fed, supplemental, deficit and full irrigation environments. The main advantage of the AquaCrop model (Raes *et al*., 2009) is that it is a user-friendly model that has merit in its optimal balance between accuracy, robustness, simplicity and it requires a relatively small number of climate, crop, soil, and management parameters. The model also uses input variables that require simple methods for their determination (Wamari *et al*. 2012; Masanganise *et al*., 2012). AquaCrop has been successfully used in parts of Sub-Saharan Africa for predicting future crop yields under climate change such as Kenya (Wamari *et al*., 2012) and Zimbabwe (Masanganise *et al*., 2012; Simba *et al*., 2013).

1.2 STATEMENT OF THE PROBLEM

Kenya has been unable to meet the rapidly increasing market demand for horticultural products like onions. As a result, Tanzania has been making up for this shortfall through exports to Kenya since the early 1990s (Sergeant, 2004). The rapid decline in soil fertility is responsible for reduced agricultural productivity (Smaling *et al*., 2002; Henao and Baanante, 2006). Climate change has also been recognized as one of the threats to sustained food production. With continued rise in global temperatures, increased water stress will be among the constraints that will diminish crop yields, and consequently crop failure owing to climate variability and change (Ponce-Hernandez and Oumer A., 2009). The majority studies conducted on climate change in Kenya's agricultural sector have analyzed the impact of the changing climate on popular crops, such as maize (Downing, 1992; Kabubo-Mariara and Karanja, 2007; Kabubo-Mariara, 2009; Mati, 2002; Karanja, 2006; and Wandaka, 2013), tomato (Karuku *et al*., 2014b) overlooking other significant crops such as the onion; the third most important vegetable crop for the local market in Kenya after *Brassica* and tomato (MOA, 2004). There is therefore need to bridge the gap between bulb onion demand and production aspects in Kenya, and with the aid of decision support tools like AquaCrop model, simulate environmental conditions so as to realize Climate Smart Agricultural (CSA) production.

1.3 JUSTIFICATION

The rapid soil fertility decline in Kenya is an environmental, soil and political time bomb. Unless measures are put in place to reverse it, agricultural food production will certainly be in jeopardy especially for the onion crop whose yields in Kenya constitute a meager 20 to 25% of those achieved by the top producing countries like India and China (Lenne *et al*., 2005). Analysis of the Kenya bulb onion market indicates that it requires extra investment focused on increasing total annual production from the current 96,000 tons of bulb onions with an average production of 15 $Mgha^{-1}$ to over 60 $Mgha^{-1}$ (USAID, 2012). Statistics show that onion production in Kenya has continued to dwindle, unable to measure up to the demand of the increasing population (FAOSTAT, 2014). High population growth rate has put more pressure on the available arable land meaning the option of increasing the acreage under onions is not feasible in Kenya (Sanginga and Woomer, 2009; Vanlauwe *et al*., 2015). A sustainable soil fertility regime under intensive agriculture provides a better option to increase onion production under a limited land resource. If the diminishing soil health is not addressed then the ominous picture is that Kenya will in the future have to solely depend on onion imports, a situation that would threaten social stability and economic development (Sanginga and Woomer, 2009).

The intensifying effects of global warming further threaten the already low onion yields due to vagaries in optimal growth requirements. Downing *et al*. (2008) indicated that Kenya would experience a rise in temperature of between 1 ^{o}C and 5 ^{o}C by the year 2050 due to climate change, while mean annual rainfall will increase mostly in the short rainy season in the humid zones which make up 20% of the Kenyan land mass. Onions require 350 – 600 mm rainfall and 12 – 25 ^{o}C temperature for optimal growth. Hence a rise of 1 to 5 ^{o}C will have a major impact on crop yields. Though it is expected that climate change and variability will impact crop yields in the Lake Victoria basin, Luedeling, (2011) affirmed that little quantitative information is available on its magnitude, thus highlighting the need for this study which is also contributing to knowledge gap on climate change degree of impact on Kenya's agricultural production.

1.4 OBJECTIVES

1.4.1 Broad Objective

To determine and forecast bulb onion yields under different soil fertility management options in West Ugenya sub-County under climate change scenarios.

1.4.2 Specific Objectives

1. To assess the effect of combined used of organic and inorganic fertilizers on soil nutrient status, and bulb onion yields under the weather conditions of West Ugenya, Siaya County.

2. To forecast potential bulb onion yields under different soil fertility management options and climate change scenarios using the AquaCrop model.

1.4.3 Hypotheses

1. Will combined use of organic and inorganic fertilizers improve soil fertility and produce highest bulb onion yields in West Ugenya sub-county?

2. Will climate change significantly impact future bulb onion productivity in West Ugenya sub-county?

CHAPTER TWO

LITERATURE REVIEW

2.1 Onion Production and Market

Onions can be cultivated through rain-fed systems or through irrigation. Generally, fertilizer requirements for onion growth and development are normally 60 - 100 kg N, 25 - 45 kg P and 45 - 80 kg K per hectare. Onions prefer medium textured soils with a pH range of 6 - 7 (Muendo and Tschirley, 2004). The crop can be established using either direct seed sowing or seedling transplanting (Muvea *et al*., 2014). Optimum soil temperature for germination is 15 – 25 °C (Jaetzold *et al*., 2009).

China is the leading producer of bulb onions in the world with over 21 million Mg followed by India at over 14 million Mg and USA (over 3.4 million Mg) while Kenya is at a paltry 0.12 million Mg (FAOSTAT, 2014). The highest productivity per hectare is in the Republic of Korea with 67 Mg ha^{-1} followed by USA (57 $Mgha^{-1}$) and Spain (54 $Mgha^{-1}$) (USAID, 2012). In Kenya, bulb onions are produced at a small scale level (Table 1) and thus market demands are not met, hence requiring importation of the produce from countries like Tanzania, Egypt and India (AFFA, 2016).

Table 1: Onion production statistics in selected counties for the period 2012 to 2014

Select Counties	**Area (Ha)**			**Production (Metric tones)**		
	2012	**2013**	**2014**	**2012**	**2013**	**2014**
Bungoma	791	913	957	21,068	23,377	27,222
Meru	346	370	374	6,543	6,900	5,419
Kajiado	163	162	172	1,790	1,671	2,035
Kisii	101	108	92	1,980	2,108	1,792
Pokot	260	160	170	3,900	2,350	2,380
Mandera	162	172	203	2,219	2,278	2,768
Laikipia	13	85	108	208	923	1,304
Siaya	32	33	37	245	438	605
Nyandarua	193	198	213	2,790	2,896	2,927
Machakos	147	148	105	1,111	828	511
Others	1,439	1,515	1,117	15,051	17,140	10,810
Total	**3,647**	**3,864**	**3,548**	**56,905**	**60,909**	**57,773**

Data Source: AFFA (2016)

2.2 Limitations of Bulb Onion Production and Yields

Though India is the second largest global producer of onion (*Allium cepa*), its production is constrained by traditional cultivation methods and the use of low yielding local seed varieties (Patel and Rajput, 2008). A study to investigate constraints to onion production and marketing in one of the major onion producing districts in India (Northern Karnataka) found that non-availability of labour during peak harvest time was the major constraint faced by farmers (Vinayak *et al*., 2013). This was largely attributed to traditional cultivation methods which solely depend on manual labour. A different study found out that crop damage due to erratic rainfall (credited to climate change) was the top most challenge faced by 76% of onion farmers in Pune district, India (Gadge and Lawande, 2012). In the U.S.A. onion thrips (*Thrips tabaci*) continues to be the significant constraint to production due to widespread resistance to insecticides that are still widely used by the industry (Schwartz, 2012). In West African states of Burkina Faso, Ghana and Côte d'Ivoire, onion producers face high seasonality, post-harvest losses of about 40%, and various production-side constraints. This limits their ability to meet domestic and regional markets, leaving the region dependent on substantial external imports during off-season months from the European Union (Braimah, 2013). In a recent study at the Bibugn Woredo district in Ethiopia, onion diseases and water shortage were found to be the major constraints in both irrigation and rain fed onion production (Berhanu and Berhanu, 2014). In Tanzania, onion seed and varieties are the main limitations to improved production (Sergeant, 2004). According to Kisetu and Joseph (2013) recommended fertilizer rates for onion are not met in Tanzania due to high costs and low capital to smallholder farmers. In Kenya, most farmers lack knowledge and skills on production and practices resulting in poor quality and low yields compared to other world producers (Muendo and Tschirley, 2004). The onion producing regions also use less than the recommended fertilizer rates except in Oloitoktok (Muendo and Tschirley, 2004). The Kenya onion enterprise needs extra investment to increase total production from the current 96,000 Mg of bulb onions with an average production of 15 $\mathrm{Mgha^{-1}}$ to over 60 $\mathrm{Mgha^{-1}}$ (USAID, 2012) due lack of value addition technologies, inaccessibility to high quality seed varieties and occurrence of high post harvest losses (AFFA, 2016).

In a field survey conducted in Kirinyaga District of Central Kenya, where commercial production of onions has been promoted since 1950s, insect pests were significantly rated as most limiting factor to production followed by diseases, lack of capital, unreliable onion market, poor weed control and inadequate supply of water for irrigation in that order (Kibanyu, 2009). Though soil fertility decline has been indicated as the major constraint to crop production in Ugenya (Mango, 1999), low quality and fake seeds have been identified as a predominant restraint where unscrupulous traders take advantage of the uneducated farmers to profit their businesses (Lenne *et al*., 2005).

2.3 Climate Change and Crop Simulation Models

Yields are the simplest expression of crop productivity, but a direct relation between yield and input use is hard to identify especially if the information is not directly registered in a bookkeeping system. Researchers have thus developed crop growth models that can create a link between yields and input use on the basis of information collected over time or by experimental methods (Donati *et al.*, 2013). Crop growth simulation models are mathematical, computer-based representations of crop growth and interaction with weather, soil and other nutrients (Rao and Wani, 2011). The two main types of crop growth models are the regression models that describe the growth trend with some empirical functions, and mechanistic models that explain the growth course from the underlying physiological processes in relation to the environment (Karuku *et al*., 2014b; Raes *et al*., 2010; and Raes *et al*., 2015). Crop simulation models can predict responses to large variations in weather and, at every point of application, weather data are the most important inputs. Currently, climate change is the big issue of concern globally with regards to agricultural productivity.

The IPCC (2007) refers to climate change as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Agricultural practices will be affected by climate change, particularly in countries like Kenya which are dependent on rain-fed agricultural systems (Karuku, 2014a, Karuku *et al*., 2014b), hence the need for crop growth simulation models for crop growth and yield forecasts.

Traditionally, complex models have been recommended for assessing yield due to their better adaptation to extreme weather and management conditions (Cabelguenne *et al*., 1999; Hansen and Jones 2000), instead of empirical models like soil organic matter (SOM) model in DSSAT (Decision Support System for Agrotechnology Transfer). However, it has been demonstrated that simple, empirical models using only weather and soil data and experimental field data, are able to provide accurate yield estimations even more than complex models.

Comparisons between empirical models and process-based crop simulation models have proved the ability for the empirical model to capture the main sources of variation in crop yield assessment. Lopez *et al.* (2014), Calviño *et al*. (2003) and Lobell and Burke (2010) compared process based models such as CROPGRO and CERES-Maize, respectively with empirical models, obtaining very satisfactory results thus demonstrating that these approaches could play an important role in impact assessment of climate change effect.

Nevertheless empirical models have limitations related to their applicability in regions under climate/crop and soil conditions clearly different to those where the calibration was carried out. Another major limitation of the empirical models is the non-consideration of weather event dynamics effects on yield simulation (Lopez *et al.*, 2014). In some areas such as the third world countries, available weather data could be limiting. For example, a project in Homa Bay and Busia districts in Kenya used proxy climate datasets of the area for modelling crop yields (Luedeling, 2011).

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Study Site

The study was conducted in Ukwala Division located 20m South of Uriya Primary School at 0123410 N and 3471403 E at an altitude of 1267 masl in West Ugenya Sub County, Kenya (Figure 1 and 2). It falls under agro-climatic zone II, classified as sub humid (Jaetzold *et al*., 2009). Ferralsols, based on WRB, (2006) classification are the dominant soil types in the study area (Jaetzold *et al*., 2009). The mean monthly temperature is 21.7 °C with March being the hottest (22.6 ^{o}C) and July the coldest (20.7 ^{o}C) months while rainfall is bimodal, with long rains occurring in March to June and short rains from September to November (Jaetzold *et al*., 2009). The physiography of the area presents a lower middle to level uplands comprising of gently undulating slopes of between 2 and 8% (Mango, 1999; Jaetzold *et al*., 2009). The major land use is intensive mixed farming accounting for 71% of the Ugenya population (KNBS and SID, 2013). Main crops grown include maize *(Zea mays)*, beans (*Phaseolus vulgaris*), sorghum *(Sorghum bicolor)*, cassava (*Manihot esculenta)* and sweet potatoes *(Ipomoea batatas)*. About 79% of the population own livestock consisting of indigenous (small East African Zebu) and cross breed cattle (Ayrshire and Friesian), goats, sheep, pigs, rabbits and poultry (KNBS, 2009).

Figure 1: Map of Kenya with location of Siaya County highlighted in red within which the study was conducted.
Image credit: NordNordWest, 2015
http://creativecommons.org/licenses/by-sa/3.0/de/legalcode

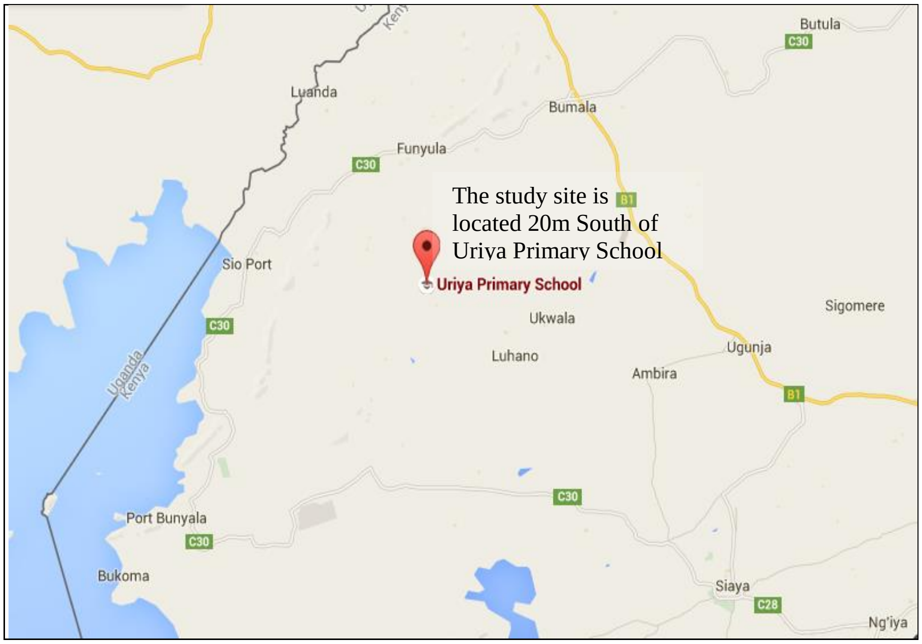

Figure 2: Map showing location of the study site in Ugenya West sub-county
Image credit: Google Maps

3.2 Experimental Layout and Design

The experimental layout was a Randomized Complete Block Design with four treatments each replicated three times, namely: T_1 (5 Mg ha^{-1} cattle manure), T_2 (46 kg P ha^{-1} x 26 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), and T_4 (half of T_1 x half of T_2). The sources of Phosphorous (P) and Nitrogen (N) were Triple Super Phosphate (TSP) containing 46% P_2O_5 and Calcium Ammonium Nitrate (CAN) containing 26% N, respectively, while composted cattle manure was obtained from a local farmer. The test crop was bulb onion *(Allium cepa* L.*)*, variety Neptune, directly planted at a spacing of 20 cm x 15 cm, at 3.1 kg ha^{-1} seed rate translating to about 300,000 plants ha^{-1}.

3.3 Soil and Manure Chemical Analysis

Initial soil characterization involved taking 6 soil samples from the experimental site with a soil auger in a transect, at 0 – 20 cm depth, and mixing them to form a 1 kg soil composite sample that was collected in a polythene bag for chemical analysis (Table 4). Another 1 kg cattle manure sample was collected by sub-sampling from a manure pit and placed in a separate polythene bag for chemical analysis (Table 2). During harvest in the two cropping seasons, plant litter on the soil surface was removed before post-soil sampling was done. Similarly, 1 kg composite soil sample was taken from each plot, replicated three times for better representation and accuracy, and analyzed for chemical properties. The samples were first air-dried, crushed and then passed through a 2 mm mesh sieve for physical and chemical analyses. Soil pH was determined with a pH meter in a ratio of 1:2.5 soil/water suspension. Soil texture was by hydrometer method as described by Glendon and Doni (2002). CEC (cation exchange capacity) of the soil and manure samples were separately determined in an ammonium acetate (NH_4OAc) solution at pH 7 and NH_4 concentration in the solution determined by Kjeldhal distillation followed by titration with hydrochloric acid. Exchangeable bases (Ca, Mg, Na and K) were extracted from the soil - NH_4OAc leachate and manure - NH_4OAc leachate respectively and determined using Atomic Absorption Spectrometry (ASS). Organic carbon in soil and manure samples was determined following the Walkley and Black (1934) method as described by Nelson and Sommers (1996). Total N was determined by micro-Kjeldhal distillation method as described by Bremner (1996). The Bray II (molybdate blue) method was used to determine available P.

Undisturbed core soil samples were also collected using core-rings in a transect at a depth of 0 - 20 cm for bulk density and saturated hydraulic conductivity (Ksat) determination. Bulk density was determined by calculating the weight of oven dried soil at 105 ^oC after 24 hours to a constant weight, divided by the soil volume, equivalent to the volume of the core rings. Porosity (P) was calculated according to Landon (2014) from the relationship;

$$P = 1 - \frac{\rho_b}{\rho_s}.100 \qquad \text{……………….…………………………………..….. (1)}$$

Where; ρ_b = Bulk density, ρ_s = Particle density

Ksat determination was by the constant head permeameter method as described by Klute and Dirksen (1982). Soil moisture retention (pF) was determined according to Hinga *et al.* (1980). Table 2 shows the chemical properties of the cattle manure used in the experiment during the two cropping seasons while Table 3 shows the inorganic fertilizer application rates for onion.

Table 2: Chemical properties of composted cattle manure used in season I and II

Parameter	Season I	Season II	Mean
Total Nitrogen (TN), %	2.1	1.9	2.0
Phosphorous (P), %	0.5	0.7	0.6
Potassium (K), %	2.1	2.6	2.4
Organic Carbon (OC), %	28.5	31.7	30.1
Carbon: Nitrogen (C:N) ratio	13.6	16.7	15.2
Calcium (Ca), %	5.3	4.8	5.1
Magnesium (Mg), %	0.7	0.7	0.7

3.4 Agronomic Practices

Land was tilled using oxen plough, and hand hoes used to prepare 40 m x 1 m raised beds at 10 cm above the ground with 1 m boundary between the raised beds. Onion seeds were sown directly along 5 cm deep furrows on the raised beds, and covered lightly with soil at the beginning of September 2015 in season I, and March 2016 in season II. The raised beds received the different fertilizer application rates corresponding to the treatments being studied on onion yields (Table 3). The germinated onion seeds were thinned to attain a spacing of 15 cm within rows and 20 cm between rows, 6 weeks after emergence. Hand weeding was done after every 4 weeks or any time the weeds emerged to avoid competition for moisture, sunlight and nutrients. Twenty (20) g of Mistress 72 WP (Cymoxanil 8% + Mancozeb 64%) preventive and curative fungicide mixed with water in a 20 liters knapsack was sprayed at the onion vegetative stage to manage downey mildew, purple blotch and blight diseases, while continuous visual inspection of plants in the field was done for any signs of pest or other disease attack. Harvesting was done 130 days after crop emergence in a 1m^2 quadrant, when 80% of the crops had their leaves fallen over, by uprooting the onions from the ground by hand and sun drying for 7 days.

Table 3: Organic and inorganic fertilizer application rates in season I and II

Recommended application rates	References	Equivalent rates of recommended fertilizer applications
26 kg N ha^{-1}	Nguthi *et al*. (1994), Muendo and Tschirley, (2004)	26 kg ha^{-1} CAN (26% N)
46 kg P ha^{-1}	Nguthi *et al*. (1994)	105.4 kg ha^{-1} TSP (46% P_2O_5) i.e. $P_2O_5 = 2.292P$
5 Mgha^{-1} manure	Muriuki and Qureshi, (2001), Jaetzold *et al*. (2009)	5 Mgha^{-1} cattle manure

Legend: CAN – Calcium Ammonium Nitrate, TSP – Triple Super Phosphate, P_2O_5 - Phosphate

3.5 Crop Data

At physiological maturity, crop yield data was collected in four evenly spaced sections in each of the 40 m x 3 m plots using a 1m^2 quadrant thrown randomly. Bulb weight was computed by weighing together the bulbs inside the quadrant. The yield weight in g m^{-2} was extrapolated to Megagrams ha^{-1} by multiplying it by 0.0110231. Bulb diameter was measured using a vernier caliper at the widest point in the middle portion of the mature bulbs. The method by Nguthi *et al*.

(1994) was used to determine bulb grade where a grade 1 bulb had ≥ 5 cm diameter; $5 <$ grade 2 ≥ 3 cm and grade 3: < 3 cm.

3.6 Climate Data

Rainfall (mm), relative humidity (%), wind speed (ms^{-1}) at 2m above ground, maximum and minimum air temperature (^{0}C), and sunshine hours for the study period were obtained from the Kenya Meteorological Department station 17 km away from the study site. The data allowed for calculation of Reference Crop Evapo-transpiration (ETo) using FAO-ETo calculator version 3.2 that utilizes the Penman Monteith method (Allen *et al.*, 1998). The USDA Soil Conservation Service method as described in Allen *et al*. (1998) was used to calculate the effective rainfall in the study area. Effective rainfall is the rain water remaining in the soil after losses from runoff and deep percolation (FAO, 1978).

3.7 Statistical Analysis

Soil and crop yield data were arranged in Microsoft Excel spread sheets and imported into Genstat statistical software, 15th edition (Payne *et al.*, 2009) where they were subjected to Analysis of Variance (ANOVA). Least Significant Differences (LSD) at $\leq 5\%$ level were used to detect differences among means.

CHAPTER FOUR

Effects of Combined Use of Organic and Inorganic Fertilizers on Bulb Onion (*Allium cepa* L.) Yields

Abstract

Low yields due to declining soil fertility continues to be a major constraint to onion production in Kenya necessitating imports to meet market demand for the increasing population. A field experiment was carried out for two seasons in Ukwala division of West Ugenya Sub-County during the 2015 and 2016 short and long rains seasons, respectively to evaluate the effect of combining organic and inorganic fertilizers on the soil nutrient status and yield of bulb onion (*Allium cepa* L.). The experiment was a Randomized Complete Block Design (RCBD). Treatments, each replicated three times were: T_1 (5 Mega grams ha^{-1} cattle manure), T_2 (46 kg P ha^{-1} x 26 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), and T_4 (half T_1 x half T_2) were evaluated. Data from T_1 and T_4 at the end of the two cropping seasons showed significantly ($P \leq 0.05$) higher mean yields compared to the control. Highest bulb yield (25.2 Mg ha^{-1}) and widest bulb diameter (5.1 cm) were recorded in T_4 compared to the other treatments. T_4 also had significantly ($P \leq 0.05$) higher soil available P and total organic carbon at the end of season II compared to the other treatments in the same season. Seasonal variation in rainfall amount led to considerably lower yields in the short rains (season II), compared to long rains (season I). Observed data concluded that onion yields could be significantly increased by combining organic and inorganic fertilizers at the rates of 2.5 Mgha^{-1} cattle manure containing 2% N, 0.6% P and 2.3% K, with 23 kg P ha^{-1} x 13 kg N ha^{-1} inorganic fertilizers.

Keywords: Cattle manure, inorganic fertilizer, *Allium cepa*, yield

4.1 Introduction

The bulb onion (*Allium cepa* L.) is an important spice in foods, soups, seasoning salads and stews. It is rich in vitamin E and has a myriad of therapeutic properties such as treatment of bacterial infections like dysentery, management of ulcers, wounds, scars, asthma and also as an adjuvant therapy for diabetes (WHO, 1999).

Onions are adapted to growing in different agro-ecological zones (Nguthi *et al*., 1994) and prefer medium textured soils with a pH range of 6 - 7 (Muendo and Tschirley, 2004), optimal germination soil temperature of 15 - 25°C (Jaetzold *et al*., 2009), and can be established either by direct seeding or seedling transplanting (Muvea *et al*., 2014). Although onion has been grown in Kenya over a long time, production per land area is still low at a national average of 15 $\mathrm{Mgha^{-1}}$ compared to Korea (67 $\mathrm{Mgha^{-1}}$), Spain (54 $\mathrm{Mgha^{-1}}$), Egypt (36 $\mathrm{Mgha^{-1}}$), Ghana (17 $\mathrm{Mgha^{-1}}$) and Ethiopia (10 $\mathrm{Mgha^{-1}}$) (FAOSTAT, 2014). In most parts of Kenya just like in the study area of West Ugenya sub-county, onion is mainly grown at small scale level, and soil fertility decline through nutrient mining and degradation is the main challenge to increased yields (Mango, 1999; Jaetzold *et al*., 2009; Okalebo *et al*., 2005), alongside post harvest losses (AFFA, 2016; USAID, 2012), and pests and disease (Muvea *et al*., 2014).

Combined use of organic and inorganic fertilizers has been proposed as a solution to reverse poor soil health and low crop yields (Vanlauwe *et al*., 2002; Sanginga and Woomer, 2009; Vanlauwe *et al*., 2015; Ruganzu *et al*., 2015). For instance onion yields resulting from combined use of organic and inorganic fertilizers in a field experiment in India were significantly ($P \leq 0.05$) increased by 77% compared to no fertilizer input, and up to 45% higher yields than sole inorganic fertilizers application (Rai *et al*., 2016). This study was thus premised on the need to increase onion production in Kenya to meet growing demand through integrated soil fertility management and raise income to the local farmers.

4.2.0 Materials and Methods

The study site, experimental layout and design, soil and manure characterization, agronomic practices, crop data, climate data and statistical analysis is as outlined in Chapter 3, section 3.1 to 3.7.

4.3.0 Results and Discussions

4.3.1. Initial Soil Fertility Status

The soil (Table 4) was coarse textured, exhibiting high sand content (52%) and moderate clay, (38%) implying low water retention capacity. Hence onion crop failure was imminent in the event of a drought due to high soil water percolation. Bationo *et al.* (2012) indicated that soils of sub Saharan Africa exhibiting ≥ 35% sand have low water holding capacity and therefore prone to nutrient leaching by percolating water. In addition, the high Ksat of 64.7 mmday^{-1} in the 0-20cm soil depth, categorized as moderately rapid (Gaines and Gaines, 1994) and a moderate rating of CEC of 17.4 me 100g^{-1} (FAO, 2006) all implied significant nutrient leaching was expected, such that limited nutrient availability would hinder onion growth.

The soil was slightly acid with initial pH of 6.05 that was within the 6 – 7 optimal pH range for onion growth and development (Muendo and Tschirley, 2004). Initial organic carbon (OC) was 2.6%, and adequate (≥1.5%) based on Bationo *et al*. (2012). The mean bulk density of 1.28 gcm^{-3} and 1.21 gcm^{-3} in season I and II, respectively was low according to Hazelton and Murphy (2007), probably due to the high OC content (Alemayehu *et al*., 2016; Karuku and Mochoge, 2016) in the 0 – 20 cm depth. Low bulk density would imply no hindrance to root penetration (Landon, 2014) by the onion crop root system. Also, initial soil porosity was 55% which was within recommended range of ≥ 50% (Landon (2014) that would not limit root growth and extension.

Organic matter is an important source of soil N for crop growth through gradual decay and mineralization in the soil. Initial total Nitrogen (TN) was low at 0.17% according to FAO (2006) that classifies low N as < 0.5%. Deficiency of N would result in reduced onion yields with respect to size and weight of the bulb (Mohammad and Moazzam, 2012).

Initial available P was fairly low at ≤ 15 ppm as confirmed in earlier experiments in the study area by Mango (1999), Okalebo *et al*. (2005), Jaetzold *et al*. (2009) and Owino *et al*. (2015). This implies that the onion crops could experience poor root development, stunted growth and delay in crop maturity unless P is supplemented as either foliar spray or soil fertilizer. Chacon *et al*. (2011) reported that inadequate P inhibit cell division in the meristematic tissues and encourage premature cell differentiation within the root tip, resulting in inhibition of primary root growth of young flowering plants.

Table 4: Initial soil characterization of the study site

Parameters	Soil characterization	Very high	High	Medium	Low	Very low
Sand (%)	52	-	-	-	-	-
Silt (%)	10	-	-	-	-	-
Clay (%)	38	-	-	-	-	-
Texture class	Sandy clay	-	-	-	-	-
pH-H_2O (1:2.5)	6.05		> 7	5.5 – 7.0	< 5.5	
CEC (me $100g^{-1}$)	15.40	> 40	25 - 40	12 - 25	6 - 12	< 6
OC (%)	2.59		> 2.5	1.5 – 2.5	< 1.5	
TN (%)	0.17		> 0.7	0.5 – 0.7	< 0.5	
P (ppm)	15.00	> 46	26 - 45	16 – 25	10 - 15	< 9
K (me $100g^{-1}$)	1.50	> 1.2	0.6 – 1.2	0.3 – 0.6	0.2 – 0.3	< 0.2
Ca (me $100g^{-1}$)	12.60	> 20	10 - 20	5 - 10	2 - 5	< 2
Mg (me $100g^{-1}$)	4.90	> 8	3 - 8	1 - 3	0.3 - 1	< 0.3
Na (me $100g^{-1}$)	1.30	> 2	0.7 - 2	0.3 – 0.7	0.1 – 0.3	< 0.1
ESP (%)	7.50		> 25	20 - 25	< 20	
Bulk density (gcm^{-3})	1.21	> 1.9	1.6 – 1.9	1.3 – 1.6	1.0 – 1.3	< 1.0
Porosity (%)	54.50		>50	50	< 50	
Ksat ($mmday^{-1}$)	64.70					

Legend: CEC – Cation Exchange Capacity, OC – Organic Carbon, TN – Total Nitrogen, P – Phosphorous, K – Potassium, Ca – Calcium, Mg – Magnesium, Na – Sodium, ESP – Exchangeable Sodium Percentage, Ksat – Saturated hydraulic conductivity

Initial exchangeable K indicated high levels at 1.5 me $100g^{-1}$ (FAO, 2006), implying high ‘luxury consumption’ whereby plants take up excess K than is required for their physiological needs. In water stressed conditions, K is important particularly for maintenance of turgor pressure, accumulation and transport of metabolic products in plants (Bationo *et al.*, 2012) hence an essential nutrient for optimal crop production and yields. This is in agreement with Mageed *et al.* (2017) who noted that application of higher levels of K fertilizer in calcareous soils of Egypt where environment is arid, improved plant water status as well as growth and yield of soya beans. This implies that onion crop will be highly resilient to water stress and subsequent withering during dry spells within the short and long rainy seasons in the study area.

Initial exchangeable Ca and Mg were also high at 12.6 and 4.9 me $100g^{-1}$ soil according to rating by FAO (2006) of > 10 and > 3 me $100g^{-1}$, respectively. Ca and Mg are important in plants for enzyme activation and carbohydrate transport (Bationo *et al.*, 2012). Mg deficiency mostly results in leaf chlorosis (Hao and Papadopoulos, 2004; Keino *et al.*, 2015), while stunting of new growth in stems, flowers and roots occurs when Ca is limiting (Bationo *et al*., 2012). This implies that photosynthesis in the onion crop would not be hindered due to these macro nutrients.

Initial exchangeable Na was high at 1.3 me 100g^{-1} in the study site according to FAO, (2006) ranking of 0.7 – 2 me 100g^{-1}. Although small quantities of Na are used in plant metabolism, it is not an essential plant element hence deficiency does not appear to exhibit any symptoms on onion crop (FAO, 2006). The exchangeable sodium percentage (ESP) was below the 20 - 25% tolerance range for onions (FAO, 2006) implying it was too low to inhibit the crop's nutrient mining ability in the soil of the study site. ESP greater than 15 results in clay dispersion thereby affecting soil permeability and consequently water transmission properties (FAO, 1996).

4.3.2 Weather Conditions during Onion Development Stages

In season I, the onion seed was planted 14 days after ½ETo equaled rainfall at 2.6 mmday^{-1} (Figure 3) depicting the start of the growing period as rainfall was increasing (Karuku *et al*., 2014a). The late planting implied that potential yields would be reduced as the rain-fed crop would not receive adequate water unless supplemental irrigation was carried out. As the onion development progressed it was accompanied by 85 days humid period where rainfall maintained above the ½ETo. The humid period helped to store water in the soil for crop use as water loss from crop transpiration and evaporation from soil surface was low (FAO, 1986). End of the growing period was marked when rainfall reduced to ½ETo at 3.2 mmday^{-1}. End of the growing period come 16 days early to the 130 days requirement for onion (variety Neptune) growing period; and the inherent coarse texture of the soil could not store the water during the humid period due to its high percolation rate, which would necessitate supplemental irrigation for the crop to meet its full water requirements.

In season II, onion seed was also planted late 9 days after ½ETo equaled rainfall at 2.9 mmday^{-1} (Figure 3). The humid period in this season lasted 67 days and the growing period was shortened by 32 days compared to season I, causing premature senescence of the crop as excess water stored in the soil during the humid period was lost before crop use due to the low water holding capacity of the sandy soil. The shorter growing period compared to season I was due to reduced rainfall which had the effect of increasing the yield reduction factor and lowered onion yield, as crop water needs were higher than available soil moisture.

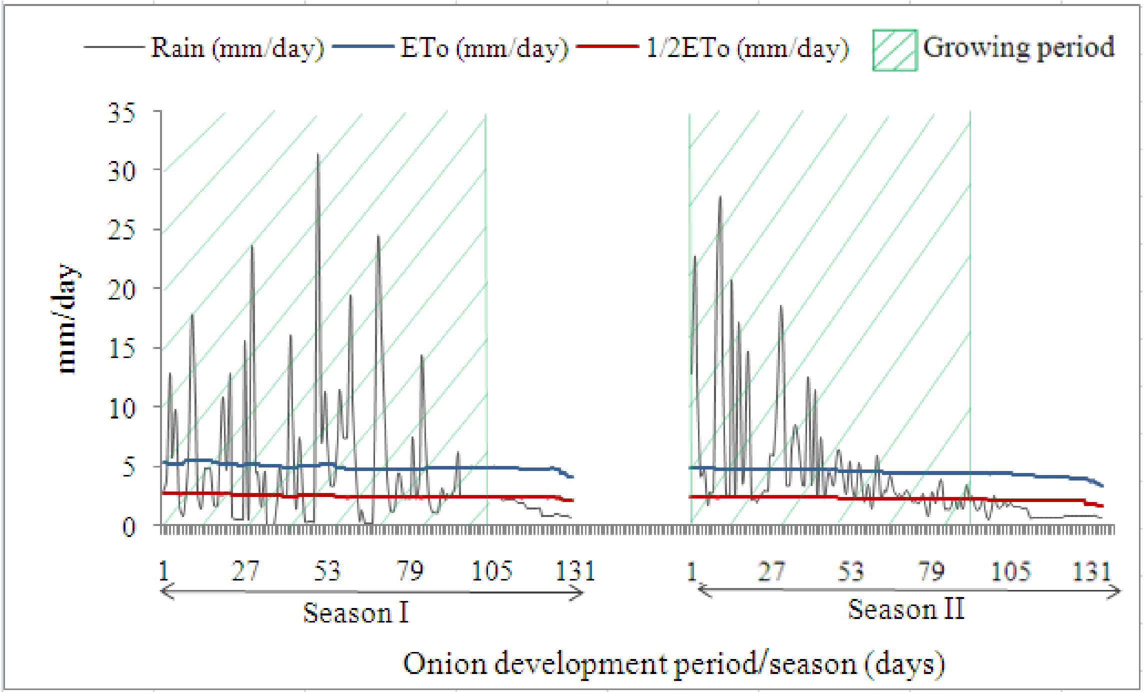

Figure 3: Rainfall, evapotranspiration (ETo) and half evapotranspiration (½ETo) during onion growing period

In season I, effective rainfall was 85.2 mm at initiation stage and continuously increased up to the end of the reproductive stage, then reduced as expected at maturation (Table 5). In season II, the initiation stage received 65.6 mm effective rainfall and increased in the vegetative and reproductive stages to 118 and 148 mm, respectively. The maturation stage saw a rainfall reduction to 53 mm, which was necessary as this stage requires relatively dry and warm weather to attain high quality onion yields, otherwise rotting and bulb splitting would occur. For instance, Karuku *et al*. (2014a) observed that an increase in precipitation in the maturation stage of tomatoes affected yield quality and quantity through fruit drops. Effective rainfall was within the 300 to 500 mm water requirement for onion optimal growth and yields (FAO, 1986), where it was higher at 413 mm throughout season I compared to 384 mm in season II. Reduced rainfall in season II compared to season I (Table 5) would imply that crop yield in season II could be lower as uptake of water and nutrients by plant roots would difficult as water is held at higher tension meaning more energy expended in water uptake that could go to yield production.

Table 5: Weather and related crop data during onion growth stages

Growth stages	Growth length (days)	Season I				Season II			
		R (mm)	ETo (mmday^{-1})	ETonion (mmday^{-1})	Tmean (^{o}C)	R (mm)	ETo (mmday^{-1})	ETonion (mmday^{-1})	Tmean (^{o}C)
Initial	15	85.2	5.1	2.6	24.6	65.5	5.4	2.7	24.1
Vegetative	25	107.9	4.9	3.7	23.2	117.5	5.5	4.1	23.4
Reproductive	70	170.4	5.0	5.3	23.6	147.7	4.8	5.0	23.5
Maturity	20	49.1	4.8	4.1	25.3	53.5	4.6	3.9	23.8

Legend: R – effective rainfall; ETo – evapotranspiration; ETonion – actual onion evapotranspiration; Tmean – mean air temperature

In season I, ETonion was between 2.6 and 5.3 mmday^{-1} during the growing period and was largely outside the 5 to 6 mmday^{-1} range that would allow the onion meet its full transpiration water requirements (FAO, 1986). In season II, ETonion ranged between 2.7 and 5.0 mmday^{-1}, and due to lower rainfall, resulted in onion water stress at reproductive stage of bulb formation that could have led to high yield reduction factor (ky) in this stage. In both season I and II, supplemental irrigation or other soil water conservation management practice such as mulching was necessary for the onion crop to meet its full water requirements.

Actual onion evapotranspiration, ET_{onion} (i.e. ETo x Kc) at the initial stage was low, 2.6 mmday^{-1} in season I and 2.7 mmday^{-1} in season II because of a low onion crop coefficient ($Kc_{initial} = 0.5$, FAO, 1986). This implied that moisture loss from the soil through the plant atmosphere continuum was dominantly due to direct evaporation from the soil surface as the crop's canopy cover was small to transpire a significant amount of water. At the onion vegetative stage ET_{onion} increased due to increase in Kc to 0.75. ET_{onion} was at its maximum at the reproductive stage since Kc had increased to its highest 1.05 value (FAO, 1986), implying that onion canopy cover had spread substantially to shade the underlying soil from the sun, hence less moisture loss through leaf surface. At maturity stage, ET_{onion} was 4.1 mmday^{-1} in season I and 3.9 mmday^{-1} in season II. This decrease in ET_{onion} was due to a steady decline in $Kc_{maturity}$ to 0.85 (FAO, 1986) due to senescence. Mean air temperature was between 23 and 25 ^{o}C in both growing seasons which was within the optimal thermal range of 15 – 25 ^{o}C for onion germination and growth (Jaetzold *et al*., 2009).

4.3.3 Soil Nutrients Status at the End of Season I and II of Cropping

There was a significant ($F = 16.33$, $P \leq 0.01$) increase in soil pH in T_1 and T_4 compared to T_2 and the control in season I (Table 6). This pH increase could have been due to high levels of lime-like materials such Ca and Mg compounds in the applied organic cattle manure (Table 2) in T_1 and T_4 that neutralized the concentration of acidifying H+ ions from the soil (FAO, 2006).

Table 6: Soil properties after harvesting the first and second season crop

	Season I					Season II				
Treatment (T)	pH (H_2O)	OC (%)	TN (%)	P (ppm)	K (me100g^{-1})	pH (H_2O)	OC (%)	TN (%)	P (ppm)	K (me100g$^{-1)}$
T_1	6.08^c	2.98^c	0.20^b	16.1^b	1.5^a	6.08^b	3.06^b	0.21^c	16.5^b	1.5^a
T_2	6.04^a	2.51^a	0.18^{ab}	17.6^c	1.4^a	5.98^a	2.56^{ab}	0.19^b	18.1^c	1.5^a
T_3	6.03^a	2.47^a	0.17^a	15.1^a	1.4^a	6.04^b	2.50^a	0.17^a	15.9^a	1.4^a
T_4	6.06^b	2.94^c	0.19^{ab}	17.2^c	1.5^a	6.06^b	3.36^c	0.21^c	17.8^c	1.5^a
SE	0.01	0.09	0.02	0.34	0.06	0.03	0.14	0.01	0.25	0.10

Legend: T_1 - 5Mgha^{-1} cattle manure, T_2 - 46kg P ha^{-1} + 26kg N ha^{-1}inorganic fertilizers, T_3 – control, T_4 - half T_1 + half T_2, SE – standard error, mean figures followed by same letter down the columns are not significantly different at $P \leq 0.05$

At the end of season II, soil pH ranged between 5.98 and 6.08 and was significantly ($F = 8.68$, $P = 0.07$) lower in T_2 compared to the other treatments probably due to a net increase in protons through nitrification process of NH_4^+ ions in CAN fertilizer ($CaCO_3$ + NH_4NO_3) applied, thereby releasing H^+ ions (Yan *et al.*, 1996; Braos *et al.*, 2015).

Comparison of soil pH in season I and season II showed no significant difference between T_1, T_3 and control. This was could have been due to vegetative onion parts in season I being returned to the soil as decomposing crop litter and acting as a buffer to pH change in season II. Organic matter contains weak acids having carboxyl group (-COOH); which dissociates to attain a negative charge (-COO-) thus buffering soil pH (FAO, 2005). However, T_2 was characterized by a significant pH reduction in season II compared to season I probably due to a net increase in H+ ions beyond the buffering capacity of the soil by organic matter from leaf litter. The pH increase could also have been due to plant nutrient uptake whereby attraction of soil nutrient cations to the charged surface of root hair cells caused the plant root hairs to release H+ ion which acidified the rhizosphere (Henkel, 2015).

At the end of season I and season II, there was a significantly higher ($P \leq 0.05$) OC and TN in T_1 and T_4 compared to the control. This might be attributed to decomposition of cattle manure in both T_1 and T_4, in addition to organic residues arising from decomposition of crop litter fall during the onion growing period. Application of organic manure as well as decomposition of crop litter can significantly increase soil OC (Bedada *et al.*, 2014; Cotrufo *et al.*, 2015; Novara *et al.*, 2015; Mariaselvam *et al.*, 2014) and TN (Abbasi *et al.*, 2015 and Mahmoud *et al.*, 2009). Despite inorganic fertilizer application that indirectly increased OC by up to 2% above the control, from organic matter arising from high vegetative growth that was returned to the soil as decomposing plant litter, T_2 showed no statistical difference to T_1, T_4 and the control. This may be due to the sandy nature of the soil (Table 6) that promoted leaching of salts in applied inorganic fertilizer beyond the rooting zone of the onion crop. Tropical soils with high sand content (≥ 35%) are highly susceptible to leaching of nutrients (Bationo *et al.*, 2012). Leaching reduced vegetative growth vigor in T_2 compared to T_1 and T_4 that resulted in lower litter fall that would have otherwise mineralized to add to the soil OC and TN stock.

Due to inorganic P fertilizer application, significantly ($P \leq 0.05$) higher soil available P was observed in T_2 and T_4 in comparison to T_1 and the control, at the end of the two onion growing seasons. T_1 with sole cattle manure application had significantly ($P \leq 0.05$) lower soil available P compared to T_2 and T_4 in both seasons because in contrast to inorganic fertilizers, the P concentration in livestock manures is much lower (Bationo *et al*., 2012).

There was no significant change in exchangeable K across all treatments in season I compared to the initial soil K status. This is because Ferralsols, the soils of the study area, are dominated by low activity clay minerals, mainly kaolinite (WRB, 2006), which have inaccessible inter-layers due to hydrogen bonding that prevents K fixation (Tran, 2010; WRB, 2006). Similarly, no significant difference in K across all treatments was observed in season II due to the reason adduced above on K fixation. There was no statistically significant difference in K between season I and season II probably due to luxury crop uptake (FAO, 2006). Also, K is prone to leaching especially in areas with heavy rainfall (Keino *et al*., 2015), as is the case in the study area, hence additions from cattle manure application in T_1 and T_4 could have been lost through moderate leaching in the study area.

4.3.4 Bulb Onion Yield at the End of season I and II

In season I, the yields ranged between 20.3 and 25.2 $Mgha^{-1}$ (Table 7). T_1 and T_4 had significantly ($P \leq 0.05$) higher mean onion yields, 15% and 19% above the control, respectively. This is attributed to the nutrients retained on the soil surface being available for plant uptake in the cattle manure that could have reduced leaching (Bationo *et al.*, 2012), unlike T_2 where much of the applied inorganic fertilizer could have leached with increasing rainfall. According to Vanlauwe *et al*. (2002), Okalebo *et al*. (2005), and Ruganzu *et al*. (2015), addition of organic materials improves the soil chemical, physical and biological properties that enhance nutrient availability, retention and uptake by crops. This is also in agreement with Otinga *et al*. (2013) who found application of composted cattle manure increased maize yields compared to sole use of inorganic P fertilizer.

While there were no significant differences between onion yields of T_1 and $T_{4,}$ mean separation data indicated that T_4 had 4% more yield than T_1. Higher yields in T_4 could have been due to organic fertilizer that gradually released its nutrients, further supplemented with inorganic fertilizer that released nutrients more readily, thus increasing T_4 nutrient status compared to T_1. Studies have shown that combined use of organic manures with inorganic fertilizers significantly increase soil nutrients uptake by plants and maximizes yields compared to sole application of either organic or inorganic fertilizers (Rai *et al.*, 2016; Sanginga and Woomer, 2009; Vanlauwe *et al.*, 2015).

There was no significant difference between onion yields of T_2 and the control in season I mainly because heavy rains in the initial growth stage dislodged and damaged the young onions plants thus reduced plant population and expected yield in a large section of T_2 plots. Gaping to replace the destroyed onion seedlings was not done as it would have required three more weeks to sow afresh onion seeds, that would have resulted in non-uniform growth as the gap replacement onion crop would not have attained maturity by the time yield of the remaining majority onion crop that withstood dislodging and damage was being determined.

In season II, trend in the results were similar to season I and yields significantly ($P \leq 0.05$) varied between 12.3 and 16.3 $Mgha^{-1}$. The highest onion mean yields were recorded in T_4 at 16.3 $Mgha^{-1}$ with the lowest in the control. Thus, the addition of organic materials to soil improved the chemical, physical and biological properties that enhance availability of nutrients and their uptake by crops (Otinga *et al*., 2013 and Ruganzu *et al*., 2015).

Table 7: Onion yields (Mgha^{-1}) as affected by the different treatments

Treatment (T)	Season I	Season II
T_1	24.1^b	16.2^d
T_2	20.7^a	12.9^c
T_3	20.3^a	12.3^c
T_4	25.2^b	16.3^{cd}
SE	1.2	1.9

Legend: T_1 – 5 Mg ha^{-1} cattle manure, T_2 – 46 kg P ha^{-1} + 26 kg N ha^{-1} inorganic fertilizers, T_3 – unfertilized control, T_4 - half T_1 + half T_2, SE – standard error, mean figures followed by same letter in the rows or columns are not significantly different at $P \leq 0.05$

No significant differences were observed between T_2 and the control. This is probably due to lower rainfall in season II that could have caused low availability of inorganic fertilizer in T_2 which did not to fully dissolve, and probably burnt the onion seedlings. Hergert *et al*. (2012) found out that reduced crop emergence and stand in maize, sorghum and soya bean can occur when soil moisture is limited and fertilizer is placed too close to the seed, as this increases salt concentration which interferes with root development.

Also, no significant difference was observed in mean onion yields between T_1 and $T_{4,}$ both at 24% higher than the control. It would have been expected that T_4 with higher nutrient content from the combination of organic and inorganic sources, would give higher onion yields compared to T_1. However, this was not the case because most of the inorganic nutrients in T_4 could have been bound with organic cattle manure thus temporarily immobilizing nutrients (Vanlauwe *et al*., 2002).

Mean yields comparison between seasons and treatments showed that season I was higher at 22.5 Mgha^{-1}compared to season II at 14.4 Mgha^{-1}. The difference in yield was due to the low rainfall of 286 mm in season II which was a limiting factor in contrast to season I at 390 mm (Table 5) as it provided less water to the sandy soil with inherent low water holding capacity. The soil moisture was insufficient for optimal onion transpiration needs leading to low yields as Zhang *et al*. (2004) found in wheat yields under varying levels of soil water deficit, as onions require 350 – 600 mm rain for mean yields of 17 Mgha^{-1} in the study area (Jaetzold *et al*., 2009).

4.3.5 Effect of Fertilizer Inputs on Bulb Onion Size

Bulb diameter ranged between 3.9 and 5.1cm in season I, giving finest quality of grade 1 and 2 onions (Table 8). T_4 resulted in significantly ($P \leq 0.05$) larger bulb diameters of grade 1 quality compared to all other treatments. This was due to the high nutrient content availability from applied organic and inorganic fertilizers that enhanced expansion of the bulb.

Table 8: Onion bulb diameter (cm) as influenced by the different treatments

Treatment (T)	Season I	Season II
T_1	4.9^b	3.6^c
T_2	3.9^a	2.9^{cd}
T_3	4.3^{ab}	2.7^d
T_4	5.1^b	3.6^c
SE	0.4	0.4

Legend T_1 – 5 $Mgha^{-1}$ cattle manure, T_2 – 46 kg P ha^{-1} + 26 kg N ha^{-1} inorganic fertilizers, T_3 – unfertilized control, T_4 - half T_1 + half T_2, SE – standard error, mean figures followed by same letter in the rows or columns are not significantly different at $P \leq 0.05$

The smallest bulb diameter of 3.9 cm was recorded in T_2 probably due to lowered soil N status by soil bacteria that utilized the nitrate fertilizer for their tissue development, and also converted the nitrates to nitrous oxide gas that was lost to the atmosphere. Several studies (Abbasi *et al*., 2015; Giles *et al*., 2012; and Ward *et al*., 2009) have indicated that denitrification is a dominant N loss process after leaching. N is essential for bulb enlargement (Mohammad and Moazzam, 2012), hence insufficient amounts remaining in the T_2 plots could have contributed to reduced bulb yield and grade.

The control performed 9% higher in yielding better quality bulbs than T_2 due to: (1) heavy rains that caused complete damage to a section of the experimental plots in T_2 were some onion crops were dislodged from the soil due to their under-developed rooting system at the initial growth stage, consequently reducing plant population of T_2, and hence mean yields, (2) Immobilization of the added nitrate from CAN fertilizer application by soil bacteria into their cells, in addition to nitrate conversion to nitrous oxide (N_2O) by the same soil bacteria during the growing period (Abbasi *et al*., 2015; Giles *et al*., 2012; and Ward *et al*., 2009), denied the crop adequate N required for dry matter production and bulb enlargement. However, this yield data differs from several others (Mahmoud *et al*., 2009; Bedada *et al*., 2014; Otinga *et al*., 2013) where inorganic fertilizers have been found to perform better by giving higher crop yields due to increased soil fertility status compared to an unfertilized control.

Bulb diameter in season II ranged between 2.7 and 3.6 cm. There were no statistical differences between T_1 and T_4; however they both resulted in significantly ($P \leq 0.05$) larger grade 2 bulbs compared to T_2 and the control. This could have been due to the presence of organic matter that improved soil structure and hence water holding capacity and retention of nutrients. Bedada *et al*. (2014) found that addition of either organic manure alone or in combination with inorganic fertilizers improved soil properties and crop productivity, compared to control and sole inorganic fertilizer addition in experiments on small holder farms in Ethiopia. The control had the smallest mean bulb diameter of 2.7 cm in season II due to low soil nutrient availability hence poor crop growth and development as established by Mahmoud *et al*. (2009) on spinach (*Spinacia oleracea L*.) grown on clay and sandy soils in Egypt. There were no statistically significant differences between T_2 and the control even though T_2 performed 6% better. This was due to significant loss of applied N through leaching in the sandy nature of the study site's soil that reduced nutrient status of T_2 to near that of the control.

Comparison of season I and season II showed that a higher mean bulb diameter of 4.5 cm was attained across all the treatments in season I, compared to 3.2 cm in season II. This difference was due to less rainfall being a limiting factor in season II. Karuku *et al*. (2014a) affirms that in sub-Saharan Africa, water is most critical in limiting crop production and yields. The finding by Robinson *et al.* (2013) asserts that seasonal and not annual precipitation better explains plant productivity. Zhang *et al*. (2004), FAO (2006) and Mageed *et al*. (2017) agree that deficiency in soil water affects biochemical processes for crops nutrient uptake that reduces yields.

4.5. Conclusion

From data of two growing seasons, T_4 consisting of 2.5 Mgha^{-1} cattle manure in combination with inorganic fertilizers (23 kg P ha^{-1} x 13 kg N ha^{-1}) gave the highest increase in onion yields of between 19 and 24% on bulb weight, and 16 to 25% on bulb diameter in comparison to the unfertilized control. Thus, integrated soil fertility management option of use of organic manure and inorganic fertilizer resulted in highest yields due to increased soil nutrient availability and crop uptake, and should be recommended in the study area for sustainable bulb onion farming.

CHAPTER FIVE

Simulating Climate Change Impacts on Onion (*Allium cepa*) Yields under Different Soil Fertility Management Practices in Sub Humid West Ugenya Sub-County, Kenya

Abstract

There is high confidence among scientist that climate change will occur, however the magnitude at which it will impact crop yields in different agro ecological zones will vary. Hence, this study intended to simulate the scale at which climate change will impact future onion (*Allium cepa* L.) production under special soil fertility management practices in a sub humid agro ecological zone of Kenya. AquaCrop model version 5.0 was selected to run simulations on onion yields under baseline (1986 - 2005) climate and a predicted future (2020 – 2039) climate under Relative Concentration Pathway (RCP) 4.5 and 8.5 scenarios. The model was first calibrated using two seasonal yield data of bulb onion in the sub humid study area under four soil fertility treatments, namely: T_1 (10 Mgha^{-1} cattle manure), T_2 (56 kg P ha^{-1} x 60 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control) and T_4 (combination of ½ T_1 x ½ T_2). Yield forecasts for the 2020 – 2039 scenarios ranged between 8 and 17 Mgha^{-1} indicating yield decrease of 4 to 10% in comparison to the 9 to 17 Mgha^{-1} yield of the baseline period. However, T_4 exhibited significantly higher ($P \leq 0.05$) yields compared to the other treatments in all cropping seasons and climate scenarios due to higher water productivity. The crop growth period was reduced by 14 to 16 days in all treatments in the predicted 2020 – 2039 climate scenario compared to the baseline due to increasing air temperature and CO_2. Mulching as one of the management options incorporated in the model mitigated predicted future crop yield decrease by increasing crop water productivity that doubled yields in T_2 and T_3, thus proving to be a sustainable measure to safeguard future onion yields in the study area when water is limiting. The predicted results indicate that supplemental irrigation would result in highest mean yield increase of 33% above those under mulching. The study concluded that between the years 2020 – 2039, climate change will have a negative impact on onion in the study area, reducing yields under different soil fertility management practices by up to 10% unless adaptation measures like mulching or supplemental irrigation are implemented to reverse this projected outcome.

Keywords: AquaCrop, Climate change, Sub humid zone, *Allium cepa* yields, Water productivity

5.1 Introduction

The International Panel on Climate Change, IPCC (2007) refers to climate change as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and persists for an extended period, typically decades or longer. Agricultural practices are being affected by climate change, particularly in countries dependent on rain-fed agriculture like Kenya (Karuku *et al*., 2014b). In West Ugenya Sub County of Siaya County, rainfall unreliability has been constraining agricultural production (Mango, 1999; and Herrero *et al*., 2010), and this is linked to the effects of climate change. This calls for the need to forecast yields so as to determine its magnitude and develop mitigation and adaptation measures. Traditionally, crop yield estimates have been based on empirical data until recently, however crop growth simulation models such as AquaCrop have been used to understand the effects of genotype, soil types and management practices on crop and on climate change impact assessment on agriculture (Rinaldi *et al*. 2003; Rao and Wani, 2011).

AquaCrop simulates attainable yields of the major herbaceous crops in rain fed, supplemental, deficit and full irrigation environments (Raes *et al.*, 2010). The model has been successfully used in parts of Sub-Saharan Africa to predict crop yields under climate change in Kenya (Wamari *et al*., 2012) and Zimbabwe (Masanganise *et al*., 2012; Simba *et al*., 2013; Temba and Chung, 2011). Kenya has been unable to meet the rapidly increasing market demand for horticultural products like onion (*Allium cepa* L.) due to low yields, whereas neighboring Tanzania has been making up for this shortfall through exports to Kenya since the early 1990s (Sergeant, 2004). There is need to bridge the gap between demand and production, and with the help of decision support tools, simulate environmental conditions in the short to medium term (≤ 20 years) to provide information particularly to the policy makers to influence various beneficial activities in their regions (Ifejika *et al*., 2010).

Various crop models such as APSIM (Agricultural Production Systems Simulator), DSSAT (Decision Support System for Agrotechnology Transfer), CERES-Maize (Crop Environment Resource Synthesis) and WOFOST (World Food Studies crop growth model) have been tested but have the limitation of being complex with a lot of input data requirements compared to AquaCrop model (Sarangi, 2012; Vote *et al.*, 2015). In terms of accuracy, studies have shown that the performance of AquaCrop is at par with other, more complex models such as CropSyst and WOFOST despite its simplicity (Steduto *et al.*, 2009; Sarangi, 2012). Furthermore, unlike the previous version 4.0 which had a separate ETo calculator as companion package, AquaCrop version 5.0 has integrated it in the model (Raes *et al.*, 2015), utilizing the FAO Penman−Monteith equation (Allen *et al.*, 1998).

5.2.0 Materials and Methods

The study site, crop data and soil data and data analysis is as outlined in Chapter 3, section 3.1 to 3.7.

5.2.1 AquaCrop Model Description

AquaCrop is a water productivity model that simulates possible crop yields under rain fed, supplemental, deficit and full irrigation environments. Input parameters for the model include data on climate, crop, soil, irrigation and cultural management. Output files include crop growth, soil water balance, irrigation requirement, biomass production, yield, and water productivity. For this study, new climate files (file with CLI extension) were created from AquaCrop's climate menu. The CLI file holds together the rain (PLU file), ETo (ETo file), temperature (TMP file) and CO_2 (CO2 file) data for use in AquaCrop's simulation runs. Hence, CLI files were created for the experimental period for purposes of calibrating the model, while baseline (1986 – 2005) and future (2020 – 2039) climate data (Table 9) were created to simulate crop development and yield in the baseline and future periods. Four crop files (CRO) were created based on the growth and yield characteristics of the onion crop observed in the field for each of the four soil fertility regimes in the two growing seasons. Soil files (SOL) were based on parameterization of the soil sampled in the study site (Table 11). Initial soil water conditions before planting was set to field capacity. Irrigation files (IRR) for season I and II were created for the irrigation schedule during the crop cycle with readily available water set not to go below 35% of available water at field capacity (p-factor = 0.35) according to FAO (1998) depletion factor for onion seeds. Field management files (MAN) for mulching effect on crop yields were created for a 0% and 100% scenarios of soil surface mulch cover made up of organic residues.

5.2.2 Crop Canopy Cover Data

The growth parameters such as leaf area index (LAI) and canopy cover (CC) were recorded at radical and flag leaf emergence stage (two weeks after emergence), 1 to 2 true leaves, 3 to 4 leaves, 5 to 7 leaves and 8-12 leaves of bulb onion growth stages according to Schwartz and Cramer (2011). Data was collected in four evenly spaced sections along the 40m length of each plot, using a $1m^2$ quadrant when at least 80% of the plants within the quadrant showed characteristic of each growth stage. Leaf area (LA) was obtained by a non-destructive indirect method utilizing a linear regression model described by Corcoles *et al*. (2015), Equ. 2:

$$LA = 0.000199 + 1.277\ L \times A25 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, L is total leaf length and A25 is leaf width taken from a distance of 25% from leaf sheath.

Canopy cover (CC) was obtained by use of a conversion formula by Hsiao *et al*. (2009), Equ.3:

$$CC = 1.005\left(1 - e^{(-0.6LAI)^{1.2}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, LAI is leaf area index calculated as leaf area (LA) divided by ground area (i.e. area covered by the quadrant), e is the exponential mathematical function.

5.2.3 Harvest Index

Total biomass was first recorded as the weight of the onion bulb, roots and leaves, while yield was determined as bulb weight at the time of maturity measured in the field in $1m^2$ quadrants. Harvest index (HI) was then calculated as the percentage ratio of bulb yield to total biomass. Equ. 4.

$$HI = \frac{\text{Yield (Mgha}^{-1})}{\text{Total biomass (Mgha}^{-1})} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

5.2.4 Climate Data

Daily weather data during field experiment consisting of rainfall (mm), minimum and maximum temperature (^oC), relative humidity (%), wind speed (m/s) and sunshine hours was obtained from a station ~ 40 km from the study site (Appendix XXVI). Following the Penman-Monteith equation (Allen *et al.*, 1998), potential evapo-transpiration (ETo) was automatically calculated using the ETo calculator integrated in the AquaCrop model version 5.0 by first arranging the weather data in columns in a notepad txt file. By opening AquaCrop model, climate menu, the weather data in the txt file was imported by linking the corresponding weather data columns to those in AquaCrop. The resultant ETo file was saved in AquaCrop's 'Data' folder together with the rain (PLU file) and temperature (TMP file) files. Monthly mean CO_2 concentration data (Appendix XXVII) was obtained from the Mauna Loa observatory in Hawaii (NOAA, 2016) by arranging the data in a notepad file and importing to AquaCrop to create the CO2 file.

Best practice for climate change impact assessment in the agricultural sector according to FAO (2012) was applied in the study area. This involved obtaining baseline climate trends in the project area and the relationship between past climate and agriculture, followed by projected future climate and its impacts on yields, and possible adaptation options. The World Bank Climate Change Knowledge portal was used as the source of baseline (1986 - 2005) and future (2020 - 2039) climate data (Table 9) because it presents an easy graphic user interface and one is able to obtain climate change data for a specific location in the world by feeding in the geographical coordinates into the portal. The climate data was derived from a medium resolution (MR) global circulation model (GCM) developed by France's Institute Pierre-Simon Laplace (IPSL) denoted as IPSL CM5A MR, as its weather data gave a high Pearson correlation coefficient (r) with observed baseline mean monthly rainfall (r = 0.86), and observed baseline mean monthly temperature (r = 0.75) compared to the 14 other CMIP5 (Coupled Model Intercomparison Project) ensembles, at 1^o resolution. The assumptions made for this study were that sunshine hours for the future scenario will remain the same as the baseline period, while future wind speed measured at 2 meters above the ground will not exceed 2 ms^{-1} for the sub-humid environment.

This study intended to determine future onion yields under a future climate scenario were CO2 concentration will not significantly increase beyond current atmospheric concentrations, and a scenario where CO2 concentration goes unchecked and continues to exponentially increase. Hence, future climate projections were considered under representative concentration pathway

(RCP) 4.5 and RCP8.5 whose CO_2 files are available by default in AquaCrop version 5.0. RCPs take into account different combinations of economic, technological, demographic, policy and institutional futures (Moss *et al.*, 2010; van Vuuren *et al.*, 2011; Rogelj *et al.*, 2012). RCP4.5 scenario corresponds to a future with some form of climate policy where CO_2 concentration stabilizes at 650 ppm equivalent after the year 2100, whereas RCP8.5 is a 'business as usual' future scenario translating into high severity climate change impacts with CO_2 concentration greater than 1,370 ppm equivalent and rising in 2100. Annual CO_2 concentration for the baseline period was from the global average based on marine boundary layer air data between1980 and 2007, available by default in AquaCrop model.

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

	Baseline (1986 – 2005)				Future (2020 – 2039) RCP 4.5				Future (2020 – 2039) RCP 8.5			
Month	T_{min} (°C)	T_{max} (°C)	Rain (mm/month)	Eto (mm/day)	T_{min} (°C)	T_{max} (°C)	Rain (mm/month)	Eto (mm/day)	T_{min} (°C)	T_{max} (°C)	Rain (mm/month)	Eto (mm/day)
Jan	15.17	27.79	25.49	4.0	17.67	30.79	36.41	4.0	15.42	30.69	27.12	4.0
Feb	15.94	29.31	40.7	4.3	18.44	32.51	41.73	4.3	16.15	32.18	39.64	4.3
Mar	16.60	30.19	115.49	4.5	19.10	33.39	127.03	4.5	14.90	32.86	123.84	4.5
Apr	16.89	28.82	228.38	4.0	19.39	32.02	252.41	4.0	16.36	31.66	274.83	4.0
May	16.59	26.39	111.68	3.3	19.09	29.59	122.66	3.3	17.01	29.06	127.69	3.3
Jun	15.31	26.07	31.16	3.5	17.81	29.27	32.39	3.5	15.71	28.77	25.66	3.5
Jul	14.32	26.61	28.24	3.8	16.82	29.81	21.94	3.8	15.02	29.58	21.17	3.8
Aug	14.01	27.97	60.04	4.3	16.51	31.07	47.39	4.3	14.25	30.71	52.09	4.3
Sep	14.70	28.37	103.85	4.3	17.20	31.57	130.07	4.3	14.22	31.51	90.58	4.3
Oct	15.59	28.03	153.35	4.0	18.09	31.23	192.83	4.0	15.29	31.17	208.51	4.0
Nov	16.09	26.69	152.32	3.5	18.59	29.89	192.74	3.5	16.36	29.69	179.99	3.5
Dec	15.41	26.55	75.59	3.6	17.91	29.75	85.63	3.6	15.66	29.69	68.31	3.6

Legend: T_{min} – Minimum temperature, T_{max} – maximum temperature, Eto – Reference evapotranspiration

5.2.5 Model Calibration and Validation

Observed climate data (Appendix XXVI) and future predicted climate (Table 9) were sequentially entered into the model together with the observed soil (Table 11) and crop canopy cover data (Appendix XXVIII). The salient parameters of the model were then adjusted according to the values in Table 10 so that simulations runs could give onions yields close to those observed during the experimental period. The conformity between simulated and observed onion yields (Appendix XXI) were validated by use of the Root Mean Square Error (RMSE) (Equ. 5), an index of agreement (d) as described by Willmott *et al.* (1982) (Equ. 6), and a coefficient of efficiency (E) according to Nash and Sutcliffe (1970) (Equ. 7). The closer the RMSE value is to zero, the higher the model accuracy while the Wilmott index and Nash and Sutcliffe coefficient take values between 0.0 and 1.0, where 1.0 implies high model precision.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(s_i - o_i\right)^2}{n}}$$

…………..………………..……..……….… (5)

$$d = 1 - \frac{\sum_{i=1}^{n}\left(o_i - s_i\right)^2}{\sum_{i=1}^{n}\left(\left(o_i - \bar{o}\right) + \left(s_i - \bar{o}\right)\right)^2}$$

………………………….................. (6)

$$E = 1 - \frac{\sum_{i=1}^{n}\left(s_i - o_i\right)^2}{\sum_{i=1}^{n}\left(o_i - \bar{o}\right)^2}$$

…..……………………………….…….. (7)

Where, S_i and O_i are predicted and observed data, respectively. $\bar{O}$ is the mean value of O_i , and *n* is the number of observations.

Level of model accuracy in simulating observed mean canopy cover was by use of the Pearson correlation coefficient (r) (Equ. 8).

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

………..……………....…… (8)

Where, x and y are observed and simulated canopy cover data points respectively; while n is the number of observations.

Table 10: Salient parameters of AquaCrop model calibrated so as to simulate mean onion growth and yield in the study area

Description	Value								Units or meaning
	Season I				Season II				
	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	
[1] Base temperature	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	^0C
[2] Cut-off temperature	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	^0C
[3] Initial CC at 90% emergence	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	%
[4] Canopy growth coefficient	12.7	12.1	12.1	13.8	11.3	10.0	10.2	10.8	% day^{-1}
[5] Canopy decline coefficient	0.56	0.43	0.38	0.64	0.51	0.50	0.69	0.39	% GDD^{-1}
[6] Maximum canopy cover	85.0	80.0	78.0	90.0	74.0	73.0	75.0	77.0	Function of plant density (%)
[7] Water productivity (WP), as calibrated	34.7	33.0	33.5	34.3	35.0	32.2	32.0	35.0	gm^{-2}, function of atmospheric CO_2
[8] Canopy expansion growth threshold (P_{upper})	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.25	Fraction of TAW, below this leaf growth is inhibited
[9] Canopy expansion growth threshold (P_{lower})	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	As fraction of TAW, below this leaf growth is enhanced
[10] Stomata closure threshold (P_{upper})	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	Above this stomata begin to close
[11] Early canopy senescence stress coefficient (P_{upper})	0.85	0.85	0.85	0.85	0.65	0.65	0.65	0.65	Above this early canopy senescence begins
[12] Shape factor for soil-water stress	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	Moderately convex curve
[13] Reference harvest index	78.0	75.0	74.0	80.0	75.0	73.0	73.0	76.0	%

Legend: CC – canopy cover; GDD – growing degree days; TAW – total available water, T_1*- 5 Mgha*$^{-1}$ *cattle manure,* T_2 *- (56 kg P ha*$^{-1}$*x 60 kg N ha*$^{-1}$ *inorganic fertilizers),* T_3 *(unfertilized control),* T_4 *(½* T_1 *x ½* T_2*)*

5.3 Results and Discussion

5.3.1 Soil Characterization of the Study Site

AquaCrop model requires soil texture information, saturated hydraulic conductivity (Ksat), water content at permanent wilting point and field capacity of the study area. Characterization of sandy clay soil (52% sand and 38% clay) of the study site showed that soil moisture content at permanent wilting point (pF 4.2), field capacity (pF 2.0) and Ksat (Table 11) were representative for sandy clays according to Saxton and Rawls (2005). The fairly high Ksat implied moderate resistance to water flow hence modest leaching was expected in the soils of the study area as established by Gaines and Gaines (1994) in their study on the effect of soil texture and subsequent permeability rates on nitrate leaching.

Table 11: Salient soil properties of the study site for calibration of AquaCrop

Thickness (cm)	Soil texture (%)			PWP (Vol. %)	FC (Vol. %)	AWC (Vol. %)	Ksat (mmday^{-1})
	Sand	Silt	Clay				
0 – 10	52	11	37	13.6	32.8	19.2	125.0
10 - 20	51	10	39	13.6	33.2	19.6	121.3

Legend: FC – field capacity; PWP – permanent wilting point; AWC – available water capacity; Ksat – saturated hydraulic conductivity

5.3.2 Validation of simulated Yields & Canopy Cover by AquaCrop Model

In season I and II, the model simulated yields adequately in all treatments as RMSE on average was closer to zero (Table 12). The closer the RMSE is to zero, the higher the model accuracy. T_3 however had an RMSE above 0.5 in season I due to a higher divergence between simulated and observed mean yields, lowering the performing efficiency of the model. The Willmott index of agreement (d) and Nash and Satcliffe coefficient (E) (Table 12) were on average 0.9, which is closer to one in both cropping seasons, indicating high model performance. Essentially, Willmott index and Nash and Satcliffe coefficient are dimensionless and may assume values ranging from $-\infty$ to +1, but the closer they are to +1, the better the model simulation performance. Hence, d, E as well as RMSE values obtained in the two growing seasons indicated that AquaCrop model satisfactorily simulated onion mean yields in the study area. Similar findings have been reported elsewhere, for instance Agbemabiese, (2015) found a RMSE of 0.09, Willmott's index of 0.99 and Nash-Sutcliffe efficiency of 0.96 while simulating onions yields under different irrigation regimes in Ghana. Similarly, Kiptum *et al*. (2013) found a RMSE of 0.38 while simulating cabbages (*Brassica oleracea*) biomass in Kenya.

Table 12: Validation result of simulated onion yields in the four treatments

	Season I				Season II			
	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
RMSE	0.35	0.49	0.68	0.25	0.42	0.49	0.19	0.37
d	0.99	0.99	0.98	0.99	0.97	0.99	0.99	0.99
E	0.99	0.97	0.95	0.99	0.98	0.95	0.98	0.96

Legend: T_1*- 5 Mgha*$^{-1}$ *cattle manure,* T_2 *- (56 kg P ha*$^{-1}$*+60 kg N ha*$^{-1}$ *inorganic fertilizers),* T_3 *(unfertilized control),* T_4 *(½* T_1 *+ ½* T_2*); RMSE - root mean square error, d – Willmott's index of agreement, E – Nash and Satcliffe coefficient*

Comparison between observed and simulated mean canopy cover against days to physiological maturity shows that Pearson correlation coefficient (r) on average equaled 0.97 in all treatments in the two cropping seasons (Figure 4 and 5). The r-values were close to one, indicating a positive linear relationship between observed and simulated canopy cover. This is because the Pearson correlation coefficient takes on values between +1 and -1, where values equal or close to +1 indicate positive model precision as was the case in this study. Similar findings were reported by Kiptum *et al*. (2013) who noted a strong relationship (r = 0.94) between observed and simulated canopy cover despite overestimation in the initial stages of cabbage growth due to model calibration with respect to number of days to maximum canopy cover and canopy decline.

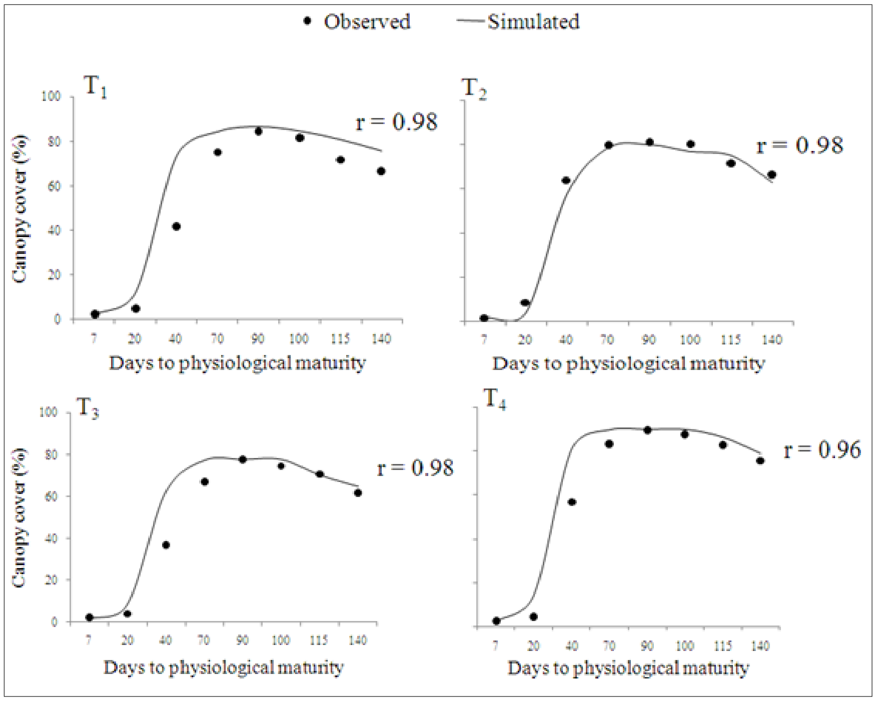

Figure 4: Observed versus simulated onion mean canopy cover in season I

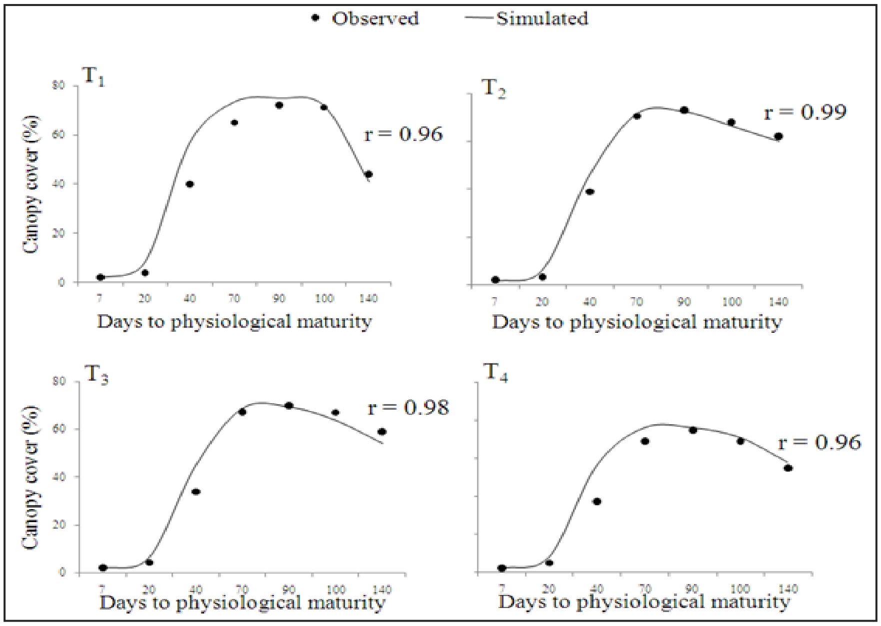

Figure 5: Observed versus simulated onion mean canopy cover in season II

5.3.3 Predicted Changes in Agro-Climate and Onion Growing Period in the Study Area

The March, April, May (MAM) long rainy season shows that rainfall will increase from 455 mm in the baseline period to 502 and 526 mm in the future under RCP4.5 and RCP8.5, respectively (Figure 6). In the September, October, November (SON) short rains season, mean rainfall will increase from 409 mm in the baseline period to 515 (RCP4.5) and 479 mm (RCP8.5) in the 2020 – 2039 future period. The MAM season will continue to have more rain than the SON season in the future except in RCP4.5, where the short rains seasons will exceed the long rains by 3%. This is because a warmer atmosphere can hold more moisture translating to increased precipitation (IPCC, 2013) as is the case of SON season under RCP4.5 that records a 0.4 ^{o}C higher temperature rise compared to the MAM season. This seasonal variation in precipitation concurs with the assessment by Downing *et al*. (2008) indicating a likely trend towards extremely wet short rains in Kenya. This implies that shifts in planting may arise where farmers who used to plant in the long rains and leave their farms fallow in short rains will take advantage of these rains to increase their food production, and as a result demand for labour and cost of cultivating the lands will increase throughout the year. This agrees with Pant (2011) who found that even with a positive impact of climate change; cost of crop production will potentially increase as a consequence of adapting to changing climatic conditions.

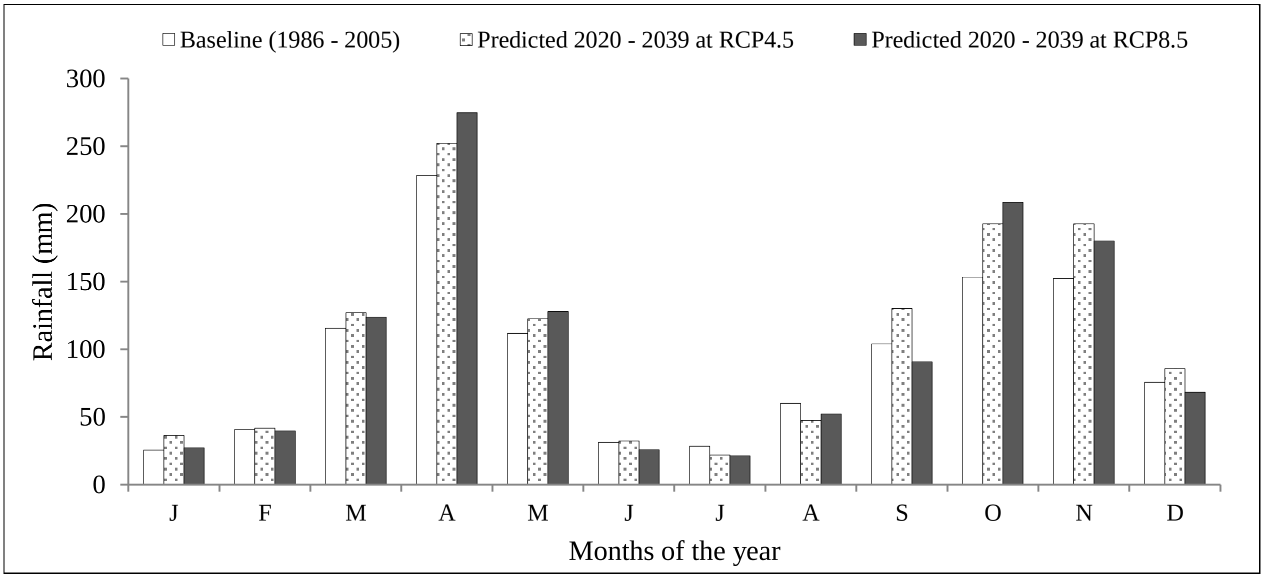

Figure 6: Mean monthly rainfall for baseline (1986–2005) and near future (2020–2039) at RCP4.5 and 8.5

Overall, annual rainfall will increase from 1,126 mm in the baseline period to 1,283 and 1,239 mm in RCP4.5 and RCP8.5, respectively. This rainfall increase is explained by the IPCC (2013), indicating that the effect of climate change on precipitation will vary, as some regions may experience less precipitation, some may have more precipitation (especially in high latitude areas), and some may have little or no change. This is due to shifts in air and ocean currents which can change weather patterns as a result of warmer atmospheric temperatures. Increased rainfall in the study area will imply higher surface runoff leading to soil erosion and also nutrient leaching due to the coarse texture nature of the soil in the study area which in turn will mean increasing the rate of inorganic fertilizer application to replenish nutrients. Letey and Vaughan (2013) established that increased leaching especially of nitrates is influenced by higher water application rates, either by rainfall or surface irrigation systems.

The MAM long rainy season will experience a rise in mean temperature from 21.4 ^{o}C in the baseline period to 23.2 ^{o}C and 22.9 ^{o}C in the projected future climate under RCP4.5 and RCP8.5, respectively (Figure 7).

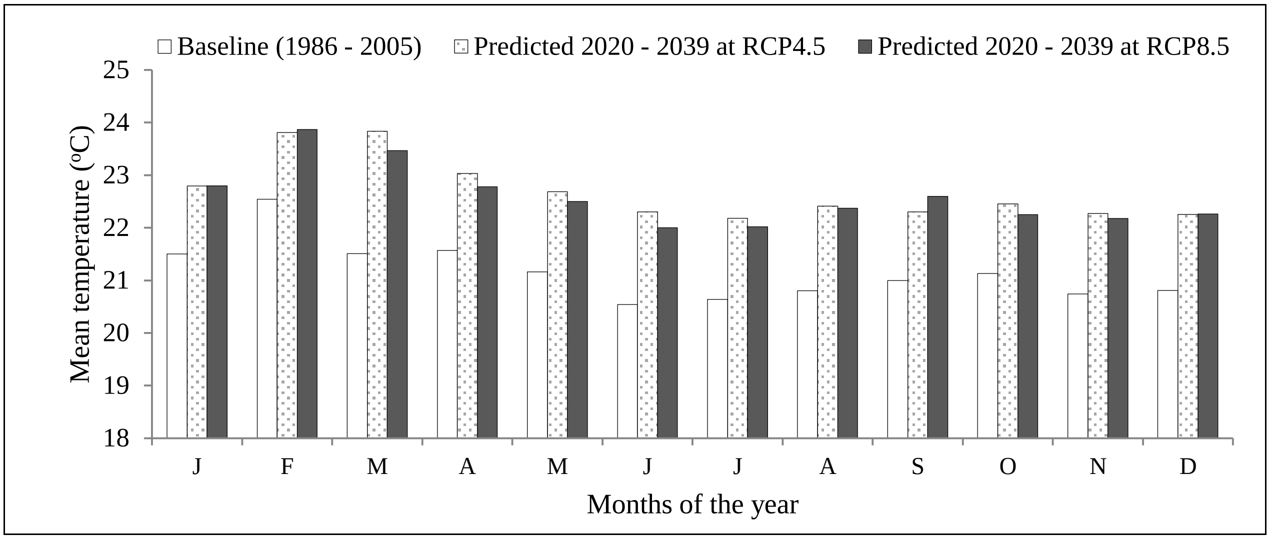

Figure 7: Mean monthly temperature for baseline (1986 – 2005) and future (2020 – 2039)

In the SON short rainy season, mean temperature will increase from 20.9 ^{o}C in the baseline to 22.3 ^{o}C in both RCPs 4.5 and 8.5. Just like in the baseline period, the months of February and March will remain the hottest in all the predicted future climate scenarios. Overall, the results indicate that mean annual temperature will increase by 1.5 ^{o}C (RCP 4.5) and 1.4 ^{o}C (RCP 8.5) relative to the baseline period. Higher and warmer temperatures especially at the reproductive and development stage of crop growth have been found to affect pollination and grain filling or fruit formation, increasing crop irrigation requirements, disrupting the length of the growing cycle and increasing the prevalence of weeds, pests and fungi (Kang *et al*., 2009; Gornall *et al*., 2010; Hatfield and Prueger, 2015). Thus future onion yields will be expected to reduce in the study area owing to increased air temperature that will reduce relative humidity and consequently the length of the growing period. However, mitigation and adaptations measures could include mulching and recycling of bio-solids such as stover back to the soil (FAO, 2008; Karuku *et al*, 2014a), conservation and minimum tillage (FAO, 2008), supplemental and deficit irrigation (FAO 2002; Karuku *et al*., 2014b; Fares *et al*., 2016), and reduced slash and burn agriculture (FAO, 2008).

The climate scenarios reduced onion growing period by an average of 16 days between the baseline and future scenarios (Table 13). The growing period is the part of the year during which local weather conditions permit normal plant growth, and its length is dependent on rainfall, evaporation and temperature, soil factors and crop factors (Karuku *et al*., 2014b). The difference in growing period between the climate scenarios was due to an increase in future air temperature relative to the baseline scenario that would increase the onion crop evapotranspiration water needs beyond soil available water, resulting in a short growing period and lowered yields due to onion wilting, if no supplemental water is provided (Rurinda *et al*., 2015; Hatfield and Prueger, 2015 and Hatfield, 2016).

Table 13: Effect of climate scenarios on onion growing period (days)

Climate scenario	Season I	Season II
Baseline	147^{bc}	151^{c}
RCP4.5	131^{a}	135^{a}
RCP8.5	131^{a}	137^{a}

Legend: Mean figures followed by same letter along the rows or down the columns are not significantly different at $P \leq 0.05$

The growing period between seasons was not significantly different in all climate scenarios despite variations in rainfall amounts seen in season I short rains versus season II long rains (Figure 6). This was probably due to the low water retention capacity of the soil's sandy clay texture which would require rain to fall in short regular intervals to prevent water stress on the onion crop, otherwise wilting would be initiated that would reduce the length of growing period.

5.3.4 Effect of Climate Scenarios on Predicted Onion Yields

Future climate scenarios will record yields of between 8 and 17 Mgha^{-1} compared to the baseline's 9 to 17 Mgha^{-1}. Future yields in the study area will reduce by between 2% and 7% in season I and season II, respectively compared to the baseline period (Table 14). This yield decrease is attributed to increase in temperature that increased the yield reduction factor (ky) per every onion development stage, lowering the crop's tolerance to water deficit. Begum and Nessa, 2014, Hatfield and Prueger, 2015, Rajaseka *et al*., 2013 all established that heat stress can cause a reduction in crop yield. Afenyo (2015) also observed that increased future temperature will lead to a level above tolerance range for most of the current crop varieties in sub Saharan Africa.

Table 14: Effect of climate scenarios on predicted onion yield (Mgha^{-1})

		Climate Scenarios		
Cropping Season	Treatment	Baseline	RCP4.5	RCP8.5
Season I	T_1	16.3^b	16.1^a	15.9^a
	T_2	15.1^a	15.0^a	15.1^a
	T_3	14.8^a	14.7^a	14.7^a
	T_4	17.2^b	17.0^b	16.7^b
Season II	T_1	11.1^b	10.5^b	11.1^b
	T_2	9.3^a	8.5^a	9.1^a
	T_3	9.0^a	8.2^a	8.9^a
	T_4	11.4^b	11.1^b	11.3^b

Legend: T_1- 5 Mgha^{-1} cattle manure, T_2 - (56 kg P ha^{-1}+60 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), T_4 (½ T_1 + ½ T_2), seasonal mean figures followed by same letter along the rows or down the columns are not significantly different at $P \leq 0.05$

Though air temperature was within onion's 15 - 25 °C (Jaetzold *et al*., 2009) thermal limit, a slight increase from 1.4 to 1.5 ^{o}C could significantly reduce yields (Polley, 2002), by decreasing the length of the reproductive growth stage. Similar observation was made by Begum and Nessa (2014) where temperature increase beyond the optimal 28 ^{o}C reduced wheat growing period, leading to sterility, and grain yield reduction. However, season I of the future period under RCP4.5 scenario showed an increase of 7% in total onion yield due to a 48 mm increase in rainfall (Figure 6) that alleviated soil moisture deficit brought about by increasing air temperature. In season I of the future climate scenarios, predicted yields ranged between 14.7 and 18.2 Mgha^{-1}. T_4 recorded significantly ($P \leq 0.05$) higher future yields compared to all other treatments due to availability of nutrients provided by both organic and inorganic fertilizers. Several studies have identified integrated use of organic and inorganic fertilizers as one way of increasing crop yields in sub-Saharan Africa (Bationo *et al*., 2012; Lambretch *et al*., 2016; Ruganzu *et al*., 2015; Rai *et al.*, 2016) over the sole use of inorganic, organic or no fertilizers. T_3 had the lowest predicted future yields due to its low soil nutrient status as it acted as control practicing traditional farming method. T_1 with cattle manure application had higher predicted onion yields than T_2 treated with nutrient rich inorganic N and P fertilizers. This is because the lattice structure of manure will hold available soil nutrients more tightly in the shallow rooting depth of the onion crop where it will be accessible for uptake compared to T_2 where nutrients will be inaccessible probably due to leaching from the inherent coarse texture of the soil. It has been established elsewhere that organic manures improve the soil water holding capacity and nutrient retention capability that benefits crops (FAO, 2005; Otinga *et al*., 2013, Ruganzu *et al*., 2015) while course textured soils experience a great deal of nutrient leaching even when applied as mineral fertilizer (Bationo *et al*., 2012; Lehmann and Schroth, 2003).

In season II also, T_4 had the highest predicted yields at 11.4 $\mathrm{Mgha^{-1}}$ followed by T_1, T_2 and T_3 in that order. The lower predicted yields in this season could have been attributed to reduced effective rainfall of 309 mm compared to that of season I of 376 mm. Robinson *et al*. (2013) found that seasonal variation in precipitation explained well variation in crop yield, with higher rainfall compared to that of a different season in the same year exhibiting increased above ground net production. Though effective rainfall was within the lower limit of 300 to 500 mm water requirement for onion's growing period, the sandy clay soil with its low moisture retention characteristic will result in yields reduction as most of the water rapidly percolates beyond the onion rooting depth.

5.3.5 Effect of Climate Scenarios on Net Irrigation Requirement and Water Productivity

In season I, NIR averages 217 mm in the baseline period and was significantly ($P \leq 0.05$) reduced to 178 and 201mm in the 2020-2039 future climate under RCP4.5 and 8.5, respectively (Table 15). This predicted future NIR decrease can be explained by leaf stomata which help plants take in CO_2 but also allow water loss through transpiration process. In CO_2 atmosphere rich environment, plants require fewer stomata implying less water loss. Thus less stomata density could have led to the observed reduction in NIR probably due to elevated CO_2 levels corresponding to reduced crop water requirement. This concurs with Fares *et al*. (2014) who observed a decrease in NIR for coffee (C3 plant) and maize (C4 plant) as a result of increased atmospheric CO_2 from 330 ppm to 550, 710 and 970 ppm. This indicates that if atmospheric CO_2 concentration keeps increasing, terrestrial plants like onion (C3 plant) will likely adapt and display reductions in transpiration losses as well as irrigation requirements (Fares *et al.*, 2014).

Table 15: Effect of climate scenarios on predicted net irrigation requirement (mm)

		Climate Scenarios		
Cropping Season	Treatment	Baseline	RCP4.5	RCP8.5
Season I	T_1	218.3^f	178.6^b	201.7^d
	T_2	218.1^f	178.4^b	201.5^d
	T_3	217.4^{ef}	177.6^b	200.7^d
	T_4	215.9^e	175.7^a	198.8^c
Season II	T_1	194.4^b	197.6^b	195.0^b
	T_2	190.6^a	192.8^a	190.5^a
	T_3	190.0^a	190.3^a	190.3^a
	T_4	193.7^a	196.3^b	193.6^a

Legend: T_1- 5 Mgha^{-1} cattle manure, T_2 - (56 kg P ha^{-1}+60 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), T_4 (½ T_1 + ½ T_2), seasonal mean figures followed by same letter along the rows or down the columns are not significantly different at $P \leq 0.05$

In season II however, predicted future NIR increased by 1.3% and 0.1% in RCP4.5 and RCP8.5, respectively. This NIR increase was significantly ($P \leq 0.05$) lower than that predicted in season I owing to variations in rainfall amounts between the long rainy season I (March to May) and short rainy season II (September to November) (Figure 6). Rainfall has been found to have an inverse relationship with NIR where a decrease in seasonal rainfall leads to an increase in NIR (Fares *et al.*, 2014; Karuku *et al.*, 2014a).

With respect to water productivity, season I had significantly ($P \leq 0.05$) lower mean onion water productivity of 3.1 kgm^{-3} in the baseline climate period compared to 3.4 and 3.3 kgm^{-3} in the predicted future (2020 – 2039) climate scenarios under RCP4.5 and 8.5, respectively (Table 16). Water productivity was defined as biomass yield in grams per cubic meter of water transpired (Raes *et al.*, 2010 and Raes *et al.*, 2015). Model's results indicated that water productivity would significantly ($P \leq 0.05$) increase in season I under climate change scenarios by 13% in both RCP4.5 and 8.5 compared to the baseline climate due to reduced opening of the stomata. When the stomata open to take in CO_2 from the atmosphere it also loses water through transpiration. With increased CO_2 in the air the plant reduces opening of the stomata. Guo *et al.* (2010) observed a positive effect of CO_2 enrichment on yield and water productivity whereby an increase in atmospheric CO_2 increased maize and wheat yields as well as water productivities compared to those without CO_2 fertilization. It has been found that elevated levels of CO_2 reduced stomata conductance and leaf transpiration thereby increasing photosynthesis and plant water use productivity in both C_3 and C_4 plants (Fares *et al.*, 2014). However, plants utilizing the C3 cycle such as onion are less efficient in photosynthetic energy fixation due to high oxygen affinity by the CO_2 acceptor leading to photorespiration compared to C4 plants where photorespiration is absent (Fares *et al*., 2014).

Table 16: Effect of climate scenarios on predicted crop water productivity (kgm^{-3})

		Climate Scenarios		
Cropping Season	Treatment	Baseline	RCP4.5	RCP8.5
Season I	T_1	3.2^b	3.5^c	3.4^c
	T_2	2.9^a	3.2^b	3.2^b
	T_3	2.8^a	3.2^b	3.1^b
	T_4	3.3^b	3.6^c	3.5^c
Season II	T_1	2.6^{bc}	2.4^{bc}	2.5^{bc}
	T_2	2.2^a	2.0^a	2.1^a
	T_3	2.2^a	1.9^a	2.0^a
	T_4	2.7^c	2.5^{bc}	2.5^{bc}

Legend: T_1- 5 Mgha^{-1} cattle manure, T_2 - (56 kg P ha^{-1}+ 60 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), T_4 (½ T_1 + ½ T_2), seasonal mean figures followed by same letter along the rows or down the columns are not significantly different at $P \leq 0.05$

Other than having a lower WP compared to that of season I, season II showed a non-significant reduction of 9% in WP both in RCP4.5 and 8.5 of the predicted 2020 – 2039 future climate compared to the baseline period. This difference in WP between seasons could be due to a 0.7 ^oC increase predicted in future air temperature of season II above the 22.3 ^oC in season I. An increase in temperature could increase the rate of soil moisture loss by evaporation especially in the surface soil layer where the shallow roots of onion crop abound, limiting water availability and consequently reducing WP and the actual crop evapotranspiration rate (ETc). A slight increase in temperature above the optimal crop requirement could also hasten leaf area decline (senescence) and thus exposing the soil to direct sunshine and moisture loss leading to less onion water use efficiency (Shah and Paulsen, 2003).

5.3.6 Effect of Mulching and Irrigation on Onion Yield under Projected Climate Scenarios

For all the climate scenarios, mulching at 100% soil surface cover indicated a significantly ($P \leq 0.05$) higher increase in mean onion yields (Table 17).

Table 17: Effect of mulching and no-mulch on predicted onion yields ($Mgha^{-1}$)

		Climate scenarios					
		Baseline		RCP4.5		RCP8.5	
Cropping season	T	0% mulch	100% mulch	0% mulch	100% mulch	0% mulch	100% mulch
Season I	T_1	16.3^{b}	18.4^{bc}	16.1^{a}	18.6^{bc}	15.9^{a}	17.4^{b}
	T_2	15.1^{a}	17.2^{b}	15.0^{a}	17.5^{b}	15.1^{a}	16.6^{b}
	T_3	14.8^{a}	17.0^{b}	14.7^{a}	17.3^{b}	14.7^{a}	16.3^{b}
	T_4	17.2^{b}	19.5^{c}	17.0^{b}	19.7^{c}	16.7^{b}	18.4^{bc}
Season II	T_1	11.1^{a}	19.9^{c}	10.5^{a}	14.7^{b}	11.1^{a}	14.7^{b}
	T_2	9.3^{a}	18.6^{c}	8.5^{a}	12.5^{b}	9.1^{a}	12.6^{b}
	T_3	9.0^{a}	18.4^{c}	8.2^{a}	12.0^{b}	8.9^{a}	12.4^{b}
	T_4	11.4^{a}	20.9^{c}	11.1^{a}	14.9^{bc}	11.3^{a}	14.9^{b}

Legend: 0% mulch - no surface mulch; 100% mulch - entire soil surface covered by mulch of organic materials; T_1*- 5* $Mgha^{-1}$ *cattle manure,* T_2 *- (56 kg P* ha^{-1} *+ 60 kg N* ha^{-1} *inorganic fertilizers),* T_3 *(unfertilized control),* T_4 *(½* T_1 *+ ½* T_2*); seasonal figures followed by same letter along the rows or down the columns are not significantly different at* $p \leq 0.05$

In all treatments mulching significantly ($P \leq 0.05$) increased onion yields compared to no mulch by 14% and 64% in season I and season II, respectively. Mulching shaded the soil and reduced the evaporative effect of the sun from reducing the soil water content. This maintained the soil moist for a longer period allowing soil nutrient uptake by the onion crop. Research has found that surface mulching either by timely inter-cultivation or by covering the soil surface with plant residues benefits crops in numerous ways as they reduce runoff and water evaporation from soil, control weeds, and adds organic matter to the soil consequently improving soil quality (Kingra and Singh, 2016), and increase soil moisture and nutrient availability to plant roots, leading to higher crop yields (Karuku *et al*., 2014a).

In all the climate scenarios and individual treatments, supplemental irrigation where readily available water was set not to go below 35% of field capacity (p-factor = 0.35) in the model, significantly ($P \leq 0.05$) increased mean onion yields by between 57 - 70%, and 97 - 148% in season I and season II, respectively compared to non-irrigation (Table 18). This yield increase could be due to sustenance of soil moisture in the coarse textured soil of the study site which exhibits a poor water holding capacity. Readily available soil water thus enabled the onion crop to easily translocate nutrients through out the growing period to attain maximum yields. Irrigation can more than double yields (FAO, 2002) as crops are able to meet their full water requirements for optimal yields.

Table 18: Effect of supplemental irrigation on predicted onion yield (Mgha^{-1})

Cropping season	T	Climate scenarios					
		Baseline		RCP4.5		RCP8.5	
		No irrigation	Sup. irrigation	No irrigation.	Sup. irrigation	No irrigation	Sup. irrigation
Season I	T_1	16.3^a	27.7^b	16.1^a	25.2^b	15.9^a	25.7^b
	T_2	15.1^a	25.8^b	15.0^a	23.7^b	15.1^a	24.5^b
	T_3	14.8^a	25.4^b	14.7^a	23.3^b	14.7^a	23.9^b
	T_4	17.2^a	28.8^b	17.0^a	26.2^b	16.7^a	26.6^b
Season II	T_1	11.1^a	29.9^c	10.5^a	21.4^b	11.1^a	21.9^b
	T_2	9.3^a	27.8^{bc}	8.5^a	17.4^b	9.1^a	18.1^b
	T_3	9.0^a	18.8^b	8.2^a	16.6^b	8.9^a	17.4^b
	T_4	11.4^a	24.6^{bc}	11.1^a	21.6^b	11.3^a	22.2^{bc}

Legend: T_1- 5 Mgha^{-1} cattle manure, T_2 - (56 kg P ha^{-1}+60 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), T_4 (½ T_1 + ½ T_2); seasonal mean figures followed by same letter along the rows or down the columns are not significantly different at $p \leq 0.05$

5.3.7 Comparison between Mulch and Supplemental Irrigation on Predicted Onion Yield

Onion yields per treatment were generally 27% higher under supplemental irrigation compared to mulching in all the climate scenarios (Figure 8). This was a significant ($P \leq 0.05$) yield increase attributed to optimal soil moisture maintained by irrigation that allowed easy translocation of soil nutrients by the root system to the different parts of the crop. Highest yield increase between treatments due to supplemental irrigation in all climate scenarios was in T_1, and was probably due to high water retention capacity of organic matter due to cattle manure applied in this treatment. Thus, cattle manure mitigated the high water infiltration rate in the soil by perhaps improving the soil structure and allowing more soil water retention and its availability by the onion crop to meet its transpiration needs. Bationo *et al*. (2012) and Otinga *et al*. (2013) confirm that organic material such as cattle manure tend to increase the proportion of soil micro pores thereby binding coarse texture soils and increase their negative charge which translates to improved water holding capacity and reduced nutrient leaching.

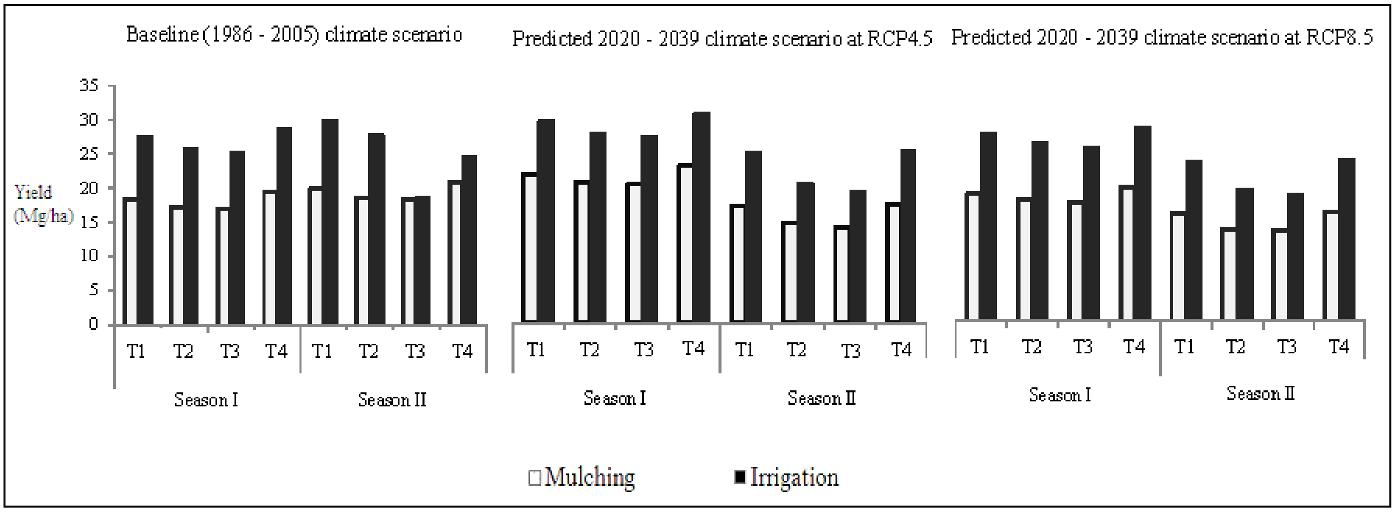

Figure 8: Mulching versus supplemental irrigation on onion yields under baseline (1986 – 2005) and predicted 2020 - 2039 climate scenarios

5.4 Conclusion

Climate change in the 2020 - 2039 future period under RCP4.5 and RCP8.5 scenarios will affect agricultural production in the study area as follows:

- It will increase air temperature by 1.5 ^{o}C which would disrupt the onion growing cycle by shortening the length of the growing period due to reduced relative humidity.
- It will increase rainfall by an average 112mm per annum that could increase surface runoff and soil nutrients leaching
- It will reduce onion yields by an average 5% in all treatments; however combined use of organic and inorganic manures exhibited in T_4 (5 Mg cattle manure ha^{-1} combined with 56 kg P ha^{-1} and 60 kg N ha^{-1}) will be the most resilient to climate change due to its lowest yield reduction compared to the other treatments.
- Climate change adaptation measures such as mulching with organic residues will increase yields by up to 64%, while supplemental irrigation will increase yields by up to 148%.
- And AquaCrop model satisfactorily simulated observed yields to warranty a level of high accuracy in predicted future yields in the study area.

The results of this study conclude that projected climate in the 2020 to 2039 period will result in a 4 to 10% decrease in onion production calling for the need for onion farmers to put in place adaptation measures such as mulching or supplemental irrigation to reverse potential yield loss.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 Discussion

Combined use of organic and inorganic fertilizers has been found to improve soil nutrient status and consequently improved crop yields (Odendo *et al.*, 2007; Otieno *et al.*, 2009; Rai *et al.*, 2016; Sanginga and Woomer, 2009; Vanlauwe *et al.*, 2002 and Wanyama, 2013) compared to the sole use of either organic or inorganic fertilizers. For instance, Rai *et al.* (2016) found that integrated use of organic and inorganic fertilizers significantly increased the uptake of N, P, K macro nutrients by onion, resulting in 7.8 tons ha^{-1} yield which was much higher compared to the sole use of organic fertilizer (6.2 tons ha^{-1}) and inorganic fertilizer (3.1 tons ha^{-1}). The beneficial concept behind organic and inorganic fertilizer combined use is that while inorganic fertilizers readily provide the essential nutrients for plant growth, organic fertilizers on the other hand release their nutrients slower through biological degradation availing their nutrients at later stages of crop development to supplement the diminishing inorganic fertilizers (Bationo *et al.*, 2012). From the results of this study, soil nutrient status was improved as OC, TN and inorganic P had increased at the end of the two cropping seasons. Improved yields through combined use of organic and inorganic fertilizers has been found for maize (*Zea mays*), Kenya's staple food crop (Otinga *et al*, 2013; and Wamari, 2012). The inclusion of improved onion yields resulting from this study adds evidence to the benefits of integrated use of organic and inorganic fertilizer use towards reversing soil fertility decline and dwindling crop yields in Kenya.

Climate change impact on crop yields in Kenya has mainly been focused on the maize crop (Downing, 1992; Kabubo-Mariara and Karanja, 2007; Kabubo-Mariara, 2009; Mati, 2002; Karanja, 2006 and Wandaka, 2013). This study presents further knowledge on climate change effect but on the horticultural sector with focus on the bulb onion. Since climate change impact will vary from one agro-ecological location to another, and from one crop species to another (IPCC, 2007 and IPCC, 2013), there is need to carry further research on projected yields of other crops, including cost benefit analysis of proposed adaptation measures such as mulching and irrigation towards sustaining current yields. Luedeling (2011) made an effort to analyze the impact of climate change on different annual and perennial crops in the Lake Victoria region;

however there is still need to understand the climate change effects under the new climate scenarios under the representative concentration pathways (RCPs) that was not considered under Ludelling (2011) study. Despite the projected changes in future crop yield, the cost benefit analysis of proposed adaptation measures such as mulching and irrigation have to be exhaustively analyzed which begs for further research.

6.2 Conclusion

This study found out that onion yields could be significantly increased in season I ($P \leq 0.05$) and season II ($P \leq 0.05$) with combined use of organic and inorganic fertilizers. Organic and inorganic fertilizers combined for this study site at rates of 2.5 $Mgha^{-1}$ cattle manure and 23 kg P ha^{-1} x 13 kg N ha^{-1} inorganic fertilizers will result in highest yields compared to unfertilized control, sole manure or inorganic fertilizer applications at rates of 5 $Mgha^{-1}$ cattle manure and 56 kg P ha^{-1} + 26 kg N ha^{-1}, respectively. The use of organic and inorganic fertilizers also gave the highest yields in the predicted future period of year 2020 to 2039 under climate change scenarios of RCP4.5 and 8.5 while lowest yields were observed in the control without fertilizer application. AquaCrop model simulated observed experimental onion yields adequately, implying that predicted future onion yields will generally decline by 4 to 10% in the 2020 to 2039 period due to climate change however; mulching with organic residues and supplemental irrigation with readily available water set not to go below 35% of field capacity, could reverse the yield decline, and further increase baseline yields by 60 to 150%.

6.3 Recommendations

- Integrated soil nutrient management where combined use of organic and inorganic fertilizers should be advocated to small scale onion farmers in Ugenya West sub-county for higher crop yields that will translate to increased incomes.
- Similar studies should be conducted on other important crops grown in Ugenya such as maize (*Zea mays*), beans (*Phaseolus vulgaris*) sorghum (*Sorghum bicolor*), cassava (*Manihot esculenta*) and sweet potatoes (*Ipomea batatas*) to determine their yield response to use of organic and inorganic fertilizer application, and predicted future yields under different climate scenarios.

- Cost benefit analysis between soil fertility management options, mulching and supplemental irrigation on onion yields should be conducted to determine the economically adaptive measure against future climate change specific to this study area, and the same extended to Siaya County and Kenya as a whole.

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APPENDICES

Appendix II: ANOVA Table for soil pH in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	0.0049	0.0016	16.33	<0.01
Residual	8	0.0008	0.0001		
Total	11	0.0057			

Appendix III: ANOVA Table for soil pH in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	0.0292	0.0097	8.68	0.07
Residual	8	0.0090	0.0011		
Total	11	0.0382			

Appendix IV: ANOVA Table for soil OC (%) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	0.6972	0.2324	27.81	<0.01
Residual	8	0.0668	0.0083		
Total	11	0.7641			

Appendix V: ANOVA Table for soil OC (%) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	2.5839	0.8613	41.29	<0.001
Residual	8	0.1668	0.0208		
Total	11	2.7508			

Appendix VI: ANOVA Table for soil TN (%) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	0.0027	0.0089	3.36	0.075
Residual	8	0.0021	0.0002		
Total	11	0.0048			

Appendix VII: ANOVA Table for soil TN (%) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	0.0030	0.0010	10.0	0.004
Residual	8	0.0008	0.0001		
Total	11	0.0038			

Appendix VIII: ANOVA Table for available P (ppm) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	11.4692	3.8231	33.24	<0.001
Residual	8	0.9200	0.1150		
Total	11	12.3892			

Appendix IX: ANOVA Table for available P (ppm) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	8.550	2.850	45.60	<0.001
Residual	8	0.500	0.062		
Total	11	9.050			

Appendix X: ANOVA Table for soil K (me100g^{-1}) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	0.0333	0.0111	3.33	0.077
Residual	8	0.0266	0.0033		
Total	11	0.0600			

Appendix XI: ANOVA Table for soil K (me100g^{-1}) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treatments	3	0.0291	0.0972	0.97	0.452
Residual	8	0.0800	0.0100		
Total	11	0.1091			

Appendix XII: ANOVA Table for onion yield (Mgha^{-1}) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	149.87	74.9	47.8	
Treatments	3	52.38	17.5	11.1	0.007
Residual	6	9.41	1.6		
Total	11	211.66			

Appendix XIII: ANOVA Table for onion yield (Mgha^{-1}) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	10.18	5.09	1.43	
Treatments	3	41.33	13.77	3.87	0.075
Residual	6	21.37	3.56		
Total	11	72.88			

Appendix XIV: ANOVA Table for bulb diameter (cm) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	0.74	0.36	2.35	
Treatments	3	2.55	0.84	5.43	0.038
Residual	6	0.94	0.15		
Total	11	4.22			

Appendix XV: ANOVA Table for bulb diameter (cm) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	0.5017	0.2508	1.40	
Treatments	3	2.0292	0.6764	3.76	0.079
Residual	6	1.0783	0.1797		
Total	11	3.6092			

Appendix XVI: ANOVA Table for the effect of climate change on onion growing period (days)

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	1386.16	693.08	332.68	
Treatments	3	6.25	2.08	1.00	0.45
Residual	6	12.50	2.08		
Total	11	1404.91			

Appendix XVII: ANOVA Table for the effect of climate change on predicted onion yields (Mgha^{-1}) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	0.1266	0.0633	4.07	
Treatments	3	9.2966	3.0988	199.21	<0.001
Residual	6	0.0933	0.0155		
Total	11	9.5166			

Appendix XVIII: ANOVA Table for the effect of climate change on predicted onion yields (Mgha^{-1}) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	0.9016	0.4508	24.22	
Treatments	3	15.4958	5.1652	277.54	<0.001
Residual	6	0.1116	0.0186		
Total	11	16.5090			

Appendix XIX: ANOVA Table for the effect of climate change on onion net irrigation requirement (mm) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	3202.93	1601.46	84783.35	
Treatments	3	13.93	4.64	245.81	<0.001
Residual	6	0.11	0.02		
Total	11	3216.97			

Appendix XX: ANOVA Table for the effect of climate change on onion net irrigation requirement (mm) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	16.89	8.45	133.97	
Treatments	3	50.17	16.72	265.20	<0.001
Residual	6	0.38	0.06		
Total	11	67.44			

Appendix XXI: ANOVA Table for the effect of climate change on onion water productivity (gcm^{-3}) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	0.189	0.095	260.31	
Treatments	3	0.378	0.126	346.74	<0.001
Residual	6	0.002	0.003		
Total	11	0.570			

Appendix XXII: ANOVA Table for the effect of climate change on onion water productivity (gcm^{-3}) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	0.151	0.075	273.52	
Treatments	3	0.716	0.238	863.89	<0.001
Residual	6	0.002	0.002		
Total	11	0.869			

Appendix XXIII: ANOVA Table for the effect of mulching on predicted yields (Mgha^{-1}) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	2.66	1.33	85.50	
Treatments	3	10.29	3.43	220.48	<0.001
Residual	6	0.09	0.02		
Total	11	13.04			

Appendix XXIV: ANOVA Table for the effect of mulching on predicted yields (Mgha^{-1}) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	91.68	45.84	600.10	
Treatments	3	15.65	5.22	68.29	<0.001
Residual	6	0.46	0.07		
Total	11	107.79			

Appendix XXV: ANOVA Table for effect of supplemental irrigation on predicted yields (Mgha^{-1}) in season I

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	11.73	5.87	127.98	
Treatments	3	17.24	5.75	125.38	<0.001
Residual	6	0.28	0.05		
Total	11	29.25			

Appendix XXVI: ANOVA Table for effect of supplemental irrigation on predicted yields (Mgha^{-1}) in season II

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Blocks	2	87.49	43.74	7.93	
Treatments	3	76.40	25.47	4.61	0.05
Residual	6	33.12	5.52		
Total	11	197.00			

Appendix XXVII: Daily weather data during season I and season II of onion cropping

Season I								Season II							
Month	Day	Rain (mm)	T_{max} (°C)	T_{min}	T_{mean} (°C)	ETo (mm/d)	$^1/_2$ETo	Month	Day	Rain (mm)	T_{max} (°C)	T_{min}	T_{mean} (°C)	ETo (mm/d)	$^1/_2$ETo
Sept	19	4.3	30	15	22.5	5.1	2.5	Mar	23	5.9	31	17	24	5.1	2.5
Sept	20	2.3	30	16	23	5.2	2.6	Mar	24	11	32	17	24.5	5.2	2.6
Sept	21	3.1	29	15	22	5	2.5	Mar	25	0	34	16	25	5.2	2.6
Sept	22	7.9	30	16	23	5.2	2.6	Mar	26	0	37	15	26	5.3	2.6
Sept	23	9.5	29	15	22	5	2.5	Mar	27	0.2	32	18	25	5.2	2.6
Sept	24	19.7	29	15	22	5	2.5	Mar	28	0.9	33	17	25	5.2	2.6
Sept	25	11.6	28	15	21.5	5	2.5	Mar	29	0.4	34	18	26	5.3	2.6
Sept	26	10.3	28	14	21	4.9	2.4	Mar	30	12.6	32	18	25	5.2	2.6
Sept	27	6.1	30	15	22.5	5.1	2.5	Mar	31	5.9	32	18	25	5.2	2.6
Sept	28	4.8	28	14	21	4.9	2.4	Apr	1	3	34	19	26.5	5.6	2.8
Sept	29	2.6	31	15	23	5.2	2.6	Apr	2	14.2	32	19	25.5	5.5	2.7
Sept	30	6.9	30	15	22.5	5.1	2.5	Apr	3	12.8	30	19	24.5	5.3	2.6
Oct	1	11.9	28	16	22	5	2.5	Apr	4	1.6	26	19	22.5	5.1	2.5

Oct	2	4.8	32	15	23.5	5	2.5
Oct	3	0.6	32	14	23	5	2.5
Oct	4	2.7	31	15	23	5	2.5
Oct	5	4.3	30	15	22.5	4.9	2.4
Oct	6	1.3	31	15	23	5	2.5
Oct	7	2.7	31	16	23.5	5	2.5
Oct	8	8.8	30	16	23	5	2.5
Oct	9	5.2	30	15	22.5	4.9	2.4
Oct	10	3.6	31	15	23	5	2.5
Oct	11	1	28	18	23	5	2.5
Oct	12	4.7	30	16	23	5	2.5
Oct	13	3.6	30	17	23.5	5	2.5
Oct	14	2.6	31	16	23.5	5	2.5
Oct	15	1.7	30	17	23.5	5	2.5
Oct	16	4	29	17	23	5	2.5
Oct	17	10	25	18	21.5	4.8	2.4
Oct	18	8	27	15	21	4.7	2.3
Oct	19	8.8	27	15	21	4.7	2.3
Oct	20	3.5	30	17	23.5	5	2.5
Oct	21	4.2	30	16	23	5	2.5
Oct	22	3.1	31	17	24	5.1	2.5
Oct	23	0.2	31	16	23.5	5	2.5
Oct	24	6.8	29	15	22	5	2.5
Oct	25	10.9	29	16	22.5	4.9	2.4
Oct	26	20.6	27	16	21.5	4.8	2.4
Oct	27	20.5	28	16	22	5	2.5
Oct	28	12.4	31	17	24	5.1	2.5
Oct	29	16.5	28	18	23	5	2.5
Oct	30	10.7	27	18	22.5	4.9	2.4
Oct	31	7.5	29	18	23.5	5	2.5
Nov	1	8.8	29	17	23	5	2.5
Nov	2	4.6	30	17	23.5	5	2.5
Nov	3	6.4	26	18	22	5	2.5
Nov	4	4.5	28	17	22.5	4.7	2.3
Nov	5	6.5	28	16	22	5	2.5
Nov	6	4.6	27	14	20.5	4.5	2.2
Nov	7	9.1	25	14	19.5	4.4	2.2
Nov	8	7.5	28	15	21.5	4.6	2.3
Nov	9	16.9	25	18	21.5	4.6	2.3
Nov	10	3.7	27	18	22.5	4.7	2.3
Nov	11	1	28	18	23	4.8	2.4
Nov	12	4.7	30	16	23	4.8	2.4
Nov	13	6.2	28	15	21.5	4.6	2.3

Apr	5	1.3	29	17	23	5.2	2.6
Apr	6	9.1	34	18	26	5.5	2.7
Apr	7	4.3	33	19	26	5.5	2.7
Apr	8	6.8	33	21	27	5.7	2.8
Apr	9	5	32	18	25	5.4	2.7
Apr	10	7.9	32	19	25.5	5.5	2.7
Apr	11	2.2	34	18	26	5.5	2.7
Apr	12	3.7	33	18	25.5	5.4	2.7
Apr	13	5.2	32	18	25	5.4	2.7
Apr	14	4.8	29	18	23.5	5.2	2.6
Apr	15	5.1	30	19	24.5	5.3	2.6
Apr	16	2.6	30	18	24	5.3	2.6
Apr	17	5.8	29	19	24	5.3	2.6
Apr	18	4.1	32	17	24.5	5.3	2.6
Apr	19	7.9	29	19	24	5.3	2.6
Apr	20	1.7	32	18	25	5.4	2.7
Apr	21	3.5	32	20	26	5.5	2.7
Apr	22	1.4	32	18	25	5.4	2.7
Apr	23	4.8	33	17	25	5.4	2.7
Apr	24	4.4	27	19	23	5.2	2.6
Apr	25	7.5	30	18	24	5.3	2.6
Apr	26	31.7	23	19	21	4.9	2.4
Apr	27	2.1	29	17	23	5.2	2.6
Apr	28	29.5	25	19	22	5	2.5
Apr	29	2.7	29	17	23	5.2	2.6
Apr	30	4	29	18	23.5	5.2	2.6
May	1	10.6	27	19	23	5.2	2.6
May	2	0.5	30	18	24	5.3	2.6
May	3	3.9	31	18	24.5	5.3	2.6
May	4	4.5	31	17	24	5.3	2.6
May	5	3.9	31	17	24	5.3	2.6
May	6	8.5	25	17	21	4.9	2.4
May	7	4.6	30	18	24	5.3	2.6
May	8	7.5	29	19	24	5.3	2.6
May	9	4.8	29	16	22.5	5.1	2.5
May	10	13.9	29	18	23.5	5.2	2.6
May	11	14.1	29	18	23.5	5.2	2.6
May	12	14.8	28	18	23	5.2	2.6
May	13	3.2	30	17	23.5	5.2	2.6
May	14	5.9	30	18	24	5.3	2.6
May	15	7.2	28	19	23.5	5.2	2.6
May	16	3.7	31	17	24	5.3	2.6
May	17	4	29	16	22.5	5.1	2.5

Nov	14	2.6	29	16	22.5	4.7	2.3
Nov	15	1.7	30	17	23.5	4.9	2.4
Nov	16	4	29	17	23	4.8	2.4
Nov	17	10	25	18	21.5	4.6	2.3
Nov	18	4.5	29	17	23	4.8	2.4
Nov	19	4.1	29	17	23	4.8	2.4
Nov	20	3.5	30	17	23.5	4.9	2.4
Nov	21	4.2	30	16	23	4.8	2.4
Nov	22	3.1	31	17	24	5	2.5
Nov	23	0.2	31	17	24	5	2.5
Nov	24	0.5	31	16	23.5	4.9	2.4
Nov	25	3.4	30	18	24	5	2.5
Nov	26	1.7	32	16	24	5	2.5
Nov	27	8.3	30	18	24	5	2.5
Nov	28	1.8	30	16	23	4.8	2.4
Nov	29	1.1	30	16	23	4.8	2.4
Nov	30	4.5	29	16	22.5	4.7	2.3
Dec	1	7.7	30	17	23.5	4.9	2.4
Dec	2	1.8	31	16	23.5	4.9	2.4
Dec	3	6.4	31	16	23.5	4.9	2.4
Dec	4	2.7	29	17	23	4.8	2.4
Dec	5	2.5	29	17	23	4.8	2.4
Dec	6	2.4	30	16	23	4.8	2.4
Dec	7	5.3	30	16	23	4.8	2.4
Dec	8	12.8	27	16	21.5	4.6	2.3
Dec	9	5.3	28	15	21.5	4.6	2.3
Dec	10	17.5	28	15	21.5	4.6	2.3
Dec	11	18.7	25	14	19.5	4.4	2.2
Dec	12	17.4	26	15	20.5	4.5	2.2
Dec	13	19.1	26	15	20.5	4.5	2.2
Dec	14	6	21	15	18	4.2	2.1
Dec	15	4.6	25	16	20.5	4.5	2.2
Dec	16	7.2	25	14	19.5	4.4	2.2
Dec	17	2.4	30	16	23	4.8	2.4
Dec	18	1.8	30	16	23	4.8	2.4
Dec	19	1.1	31	16	23.5	4.9	2.4
Dec	20	8.2	28	14	21	4.6	2.3
Dec	21	7.8	27	15	21	4.6	2.3
Dec	22	1.6	30	14	22	4.7	2.3
Dec	23	0.7	31	15	23	4.8	2.4
Dec	24	2.7	30	15	22.5	4.7	2.3
Dec	25	6.8	28	14	21	4.6	2.3
Dec	26	6.8	27	14	20.5	4.5	2.2
May	18	1	30	17	23.5	5.2	2.6
May	19	1.1	30	19	24.5	5.3	2.6
May	20	10.7	27	19	23	5.2	2.6
May	21	7.8	29	17	23	5.2	2.6
May	22	5	29	16	22.5	5.1	2.5
May	23	3.9	28	16	22	5	2.5
May	24	3.6	28	16	22	5	2.5
May	25	6.8	29	15	22	5	2.5
May	26	2.4	29	17	23	5.2	2.6
May	27	2.6	30	17	23.5	5.2	2.6
May	28	3.4	30	16	23	5.2	2.6
May	29	2.4	30	17	23.5	5.2	2.6
May	30	2.1	29	16	22.5	5.1	2.5
May	31	2.5	30	15	22.5	5.1	2.5
Jun	1	1.5	31	16	23.5	5.4	2.7
Jun	2	0	32	16	24	5.5	2.7
Jun	3	0	30	17	23.5	5.4	2.7
Jun	4	0.3	30	17	23.5	5.4	2.7
Jun	5	1.7	30	16	23	5.3	2.6
Jun	6	1.5	30	17	23.5	5.4	2.7
Jun	7	1.5	30	16	23	5.3	2.6
Jun	8	1.6	29	16	22.5	5.3	2.6
Jun	9	3.7	29	18	23.5	5.4	2.7
Jun	10	0.1	32	16	24	5.5	2.7
Jun	11	2.9	29	16	22.5	5.3	2.6
Jun	12	0.8	30	16	23	5.3	2.6
Jun	13	0	30	16	23	5.3	2.6
Jun	14	0	31	15	23	5.3	2.6
Jun	15	1.1	29	16	22.5	5.3	2.6
Jun	16	0.9	30	15	22.5	5.3	2.6
Jun	17	1.6	29	17	23	5.3	2.6
Jun	18	5.1	27	17	22	5.2	2.6
Jun	19	2.6	28	17	22.5	5.3	2.6
Jun	20	6.8	28	17	22.5	5.3	2.6
Jun	21	9.2	26	16	21	5.1	2.5
Jun	22	2.7	29	17	23	5.3	2.6
Jun	23	0	29	16	22.5	5.3	2.6
Jun	24	0	29	15	22	5.2	2.6
Jun	25	1.4	29	15	22	5.2	2.6
Jun	26	5.6	30	18	24	5.5	2.7
Jun	27	2.4	29	17	23	5.3	2.6
Jun	28	0	29	17	23	5.3	2.6
Jun	29	0	30	17	23.5	5.4	2.7

Dec	27	12.5	28	15	21.5	4.6	2.3
Dec	28	14	29	16	22.5	4.7	2.3
Dec	29	0.4	30	15	22.5	4.7	2.3
Dec	30	0.1	30	15	22.5	4.7	2.3
Dec	31	1	29	15	22	4.7	2.3
Jan	1	0	34	18	26	5.1	2.5
Jan	2	0	34	18	26	5.1	2.5
Jan	3	0	36	18	27	5.3	2.6
Jan	4	0	35	19	27	5.3	2.6
Jan	5	0	34	18	26	5.1	2.5
Jan	6	0	35	18	26.5	5.2	2.6
Jan	7	0	34	18	26	5.1	2.5
Jan	8	0.2	34	19	26.5	5.2	2.6
Jan	9	2.7	33	19	26	5.1	2.5
Jan	10	5.5	31	19	25	5	2.5
Jan	11	4.8	32	19	25.5	5.1	2.5
Jan	12	3.1	32	18	25	5	2.5
Jan	13	0.5	32	19	25.5	5.1	2.5
Jan	14	1.7	31	19	25	5	2.5
Jan	15	2	33	19	26	5.1	2.5
Jan	16	9.3	34	18	26	5.1	2.5
Jan	17	13.7	28	17	22.5	4.7	2.3
Jan	18	12.2	26	17	21.5	4.6	2.3
Jan	19	9.1	28	18	23	4.8	2.4
Jan	20	8.5	30	18	24	5	2.5
Jan	21	3.8	29	19	24	5	2.5
Jan	22	9.2	29	18	23.5	4.9	2.4
Jan	23	7	30	17	23.5	4.9	2.4
Jan	24	2.2	30	17	23.5	4.9	2.4
Jan	25	0.2	32	18	25	5	2.5
Jun	30	0	31	19	25	5.6	2.8
Jul	1	0.3	31	19	25	5.6	2.8
Jul	2	0	32	17	24.5	5.5	2.7
Jul	3	0.5	30	16	23	5.3	2.6
Jul	4	2.3	29	18	23.5	5.4	2.7
Jul	5	1.1	29	18	23.5	5.4	2.7
Jul	6	0	30	20	25	5.6	2.8
Jul	7	0	31	19	25	5.6	2.8
Jul	8	1	30	17	23.5	5.4	2.7
Jul	9	1	30	18	24	5.5	2.7
Jul	10	2.1	30	18	24	5.5	2.7
Jul	11	2.5	30	17	23.5	5.4	2.7
Jul	12	6.2	26	17	21.5	5.1	2.5
Jul	13	8.5	31	17	24	5.5	2.7
Jul	14	4.7	25	17	21	5.1	2.5
Jul	15	3.7	30	18	24	5.5	2.7
Jul	16	2.1	30	17	23.5	5.4	2.7
Jul	17	1.8	31	17	24	5.5	2.7
Jul	18	1.7	31	16	23.5	5.4	2.7
Jul	19	0.7	30	17	23.5	5.4	2.7
Jul	20	0.4	32	19	25.5	5.6	2.8
Jul	21	1.5	32	16	24	5.5	2.7
Jul	22	1.1	29	17	23	5.3	2.6
Jul	23	2.4	31	16	23.5	5.4	2.7
Jul	24	1.3	31	17	24	5.5	2.7
Jul	25	4.2	29	17	23	5.3	2.6
Jul	26	1.3	29	18	23.5	5.4	2.7
Jul	27	2	30	16	23	5.3	2.6
Jul	28	2.5	29	16	22.5	5.3	2.6
Jul	29	1.5	29	18	23.5	5.4	2.7
Jul	30	0.6	29	15	22	5.2	2.6
Jul	31	0.4	31	16	23.5	5.4	2.7

Legend: Tmin – minimum temperature, Tmax - maximum temperature, Tmean – mean temperature, ETo – reference evapotranspiration

Appendix XXVIII: Monthly mean CO_2 concentration during the experimental period

Year	Month	CO_2 (ppm)
2015	Jan	399.74
	Feb	399.47
	Mar	399.97
	Apr	400.38
	May	400.55
	Jun	400.47

	Jul	400.89
	Aug	400.81
	Sept	401.18
	Oct	401.67
	Nov	402.24
	Dec	401.63
2016	Jan	402.28
	Feb	403.22
	Mar	403.26
	Apr	404.52
	May	404.3
	Jun	404.48
	Jul	403.97
	Aug	404.13
	Sep	404.57
	Oct	404.95
	Nov	405.62
	Dec	405.20

Appendix XXIX: Observed canopy cover during onion growing period

Cropping season	Day within onion growing period	T_1	T_2	T_3	T_4
Season I	7	2.3	2.1	2.3	2.7
	20	4.9	4.1	4.1	4.6
	40	41.8	57.6	37.5	57.4
	70	75.4	78.7	67.4	83.5
	90	85.2	80.3	78.2	90.1
	100	82.0	77.2	75.0	88.0
	115	72.1	75.2	71.5	83.4
	140	67.2	63.3	62.1	76.0
Season II	7	2.1	2.0	2.0	2.0
	20	3.9	3.2	4.2	4.7
	40	39.9	38.9	33.8	37.4
	70	64.8	70.4	67.1	69.1
	90	72.0	73.2	70.4	75.2
	100	71.3	68.0	67.1	69.7
	140	44.4	62.0	59.6	58.3

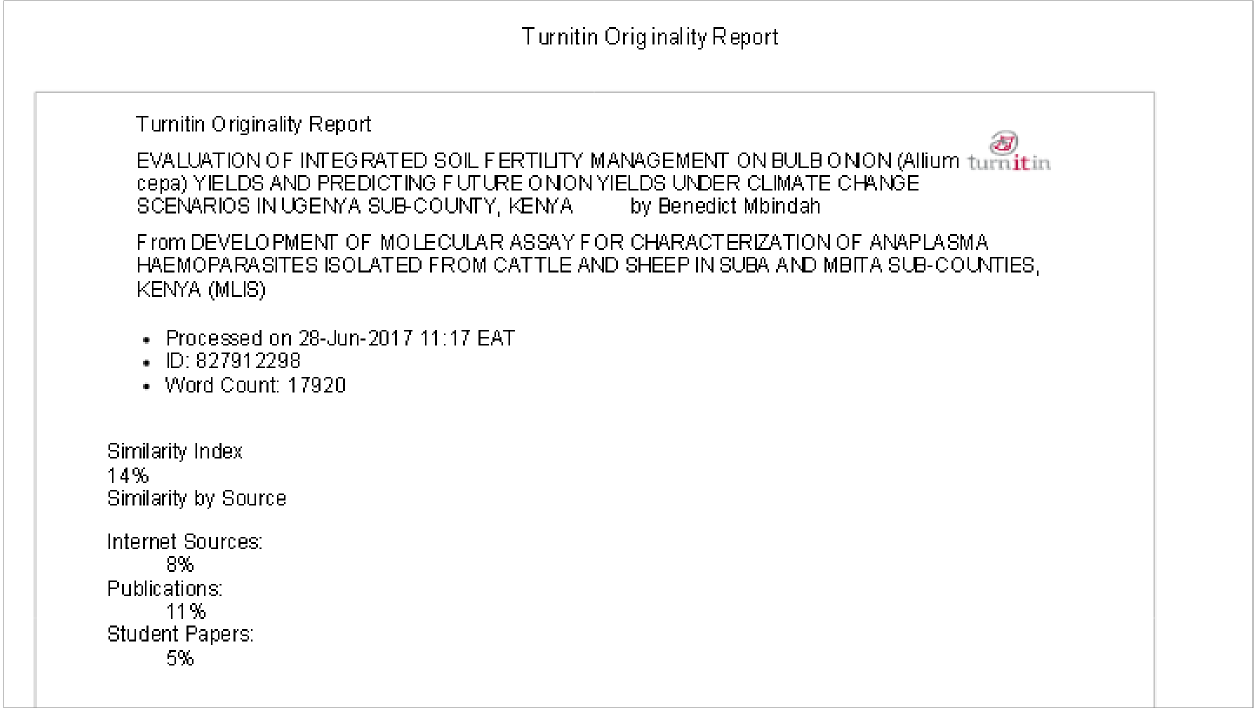
Legend T_1 *– 5 Mgha*$^{-1}$ *cattle manure,* T_2 *– 46 kg P ha*$^{-1}$ *+ 26 kg N ha*$^{-1}$ *inorganic fertilizers,* T_3 *– unfertilized control,* T_4 *- half* T_1 *+ half* T_2

Appendix XXX: Observed and simulated onion yields (Mgha^{-1}) in season I and II

		T_1			T_2			T_3			T_4		
Season I	Observed	19.3	24.4	28.6	18.0	18.9	25.3	17.5	18.5	25.0	22.2	22.3	31.0
	Simulated	19.3	23.8	25.4	19.0	19.9	25.2	18.4	19.9	24.9	21.8	22.3	27.2
Season II	Observed	14.4	17.1	17.1	11.7	11.3	15.7	12.1	10.8	13.9	14.8	18.9	15.3
	Simulated	13.7	16.7	16.6	11.6	11.8	15.1	12.2	11.1	13.9	14.7	18.2	15.2

Legend T_1 *– 5 Mgha*$^{-1}$ *cattle manure,* T_2 *– 46 kg P ha*$^{-1}$ *+ 26 kg N ha*$^{-1}$ *inorganic fertilizers,* T_3 *– unfertilized control,* T_4 *- half* T_1 *+ half* T_2

Appendix XXXIII: Plagiarism originality report



Turnitin Originality Report

Turnitin Originality Report

EVALUATION OF INTEGRATED SOIL FERTILITY MANAGEMENT ON BULB ONION (Allium cepa) YIELDS AND PREDICTING FUTURE ONION YIELDS UNDER CLIMATE CHANGE SCENARIOS IN UGENYA SUB-COUNTY, KENYA by Benedict Mbindah

From DEVELOPMENT OF MOLECULAR ASSAY FOR CHARACTERIZATION OF ANAPLASMA HAEMOPARASITES ISOLATED FROM CATTLE AND SHEEP IN SUBA AND MBITA SUB-COUNTIES, KENYA (MLIS)

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