ADAPTING NYANDO SMALLHOLDER FARMING SYSTEMS TO CLIMATE CHANGE AND VARIABILITY THROUGH MODELLING

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A research thesis submitted to the Department of Land Resource Management and Agricultural Technology in partial fulfillment of the requirements for the award of the Master Degree in Land and Water Management of the University of Nairobi.

DECLARATION

I Tobias Okando Recha, hereby declare that the work contained in this thesis is my original work and has never been submitted for a degree in any other university.

Sign:____________________________________ Date: ________________________________

This thesis has been submitted to the Board of Postgraduate Studies of University of Nairobi with our approval as supervisors:

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Dr. Lieven Claessens

DEDICATION

This work is one of the greatest achievements of my life and I dedicate it to my mother Rosemary Nakhumicha Recha and my brother Dr. John Walker Makhanu Recha for their love, support and interest to educate me. God bless you all.

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ABBREVIATIONS

CCAFS	Climate Change, Agriculture and Food Security
CMIP5	Coupled Model Intercomparison Project Phase 5
CSIRO	Commonwealth Scientific and Industrial Research Organization
DSSAT	Decision Support Systems for Agrotechnology Transfer
FAO	Food and Agriculture Organizations
FAOSTAT	Food and Agriculture Organization Statistics
GCMs	Global Climate Models
HadGEM2	Hadley Centre Global Environment Model version 2
IBSNAT	International Benchmark Sites Network for Agrotechnology
IPCC	International Panel on Climate Change
KALRO	Kenya Agricultural and Livestock Organizations
KFSSG	Kenya Food Security Steering Group
KMD	Kenya Meteorological Department
KMS	Kisumu Meteorological Station
MIROC	Model for Interdisciplinary Research on Climate
RCPs	Representative Concentration Pathways

SPSS	Statistical Package for Social Sciences
SRES	Special Report on Emission Scenarios
UNESCO	United Nations Educational, Scientific and Cultural Organization

ABSTRACT

This study was carried out in Nyando, Kisumu County to model maize production under different climate scenarios and project the yields for the years 2030 and 2050. A crop model, Decision Support System for Agrotechnology Transfer (DSSAT) was used under rain fed conditions to simulate the effects of climate change on maize production and project the future yields. Three maize varieties were used; Katumani Comp B as early maturing variety, Hybrid 511 as a medium maturing variety and Hybrid 614 as a late maturing variety.

Three global coupled models (GCMs) CSIRO-MK3-6-0, HadGEM2-ES and MIROC-ESM under representative concentration pathways (RCP) 4.5 and 8.5 were used to downscale Nyando's climate data for the years 2030 and 2050. This data together with past 50 year's climate data was entered into Weatherman and ran. Minimum annual temperatures were getting warmer by 0.0050C while maximum annual temperatures were increasing by 0.0070C. Trends in annual rainfall showed reduction in coefficient of variation from 39 % in the period 1981 to 1990 to 24% from the year 2001 up to 2015.

The projected maize yields showed that the yields will reduce in the years 2030 and 2050. This could be due to the negative effects of projected increase in temperatures in the three GCMs. However, projections showed that Katumani Comp B maize variety will have better yields compared to H511 and H614 because it requires less rain and also hardy in hot climate. The yield under RCP 4.5 for the year 2030 for Katumani Comp B was 2369 kg ha^{-1} under HadGEM while H511 had lowest projected yields of 1661 kg ha^{-1} under MIROC. Projection under RCP 8.5 for the year 2030 showed Katumani Comp B and H511 will yield 3319 and 3003 kg ha^{-1}, respectively under MIROC. The lowest simulated yields were 1867 kg ha^{-1} for H614 under CSIRO.

The maize yield projections for the year 2050 under RCP 4.5 showed that Katumani Comp B will give better yields by 3142 kg ha^{-1} under MIROC with H511 yielding lowest by 1643 kg ha^{-1} under CSIRO. The same trend was observed under RCP 8.5 with simulated yields of Katumani Comp B of 2819 kg ha^{-1} under MIROC. H614 projected lower yields of 1534 kg ha^{-1} under HadGEM. Lack of fertilizer application showed yield reduction of up to 40.8% in Katumani Comp B, 38.3% loss in H511 and 37.7% loss in H614.

In conclusion, the study found out that Katumani Comp B maize variety responded well to climate change compared to H511 and H614 maize varieties therefore well adapted in Nyando. Also, the use of DSSAT crop model was good enough to project ideal maize yields in Nyando under present and projected future climatic conditions.

Key words: Climate change, DSSAT, Global Coupled Models, Maize yield.

CHAPTER ONE

1. INTRODUCTION

1.1 Background Information

Global sectors in agriculture faces a significant need to increase production in order to provide enough food for a population projected to rise to nine billion by mid-21st century while ensuring there's environmental protection and a sustainable functioning ecosystem (Rosenzweig *et al.*,2012).Additional agricultural challenges will rise from increased emission of greenhouse gases which will exacerbate global warming resulting into changes in all components of climate system that are long lasting, severe and irreversible on the people and the ecosystems (IPCC, 2014). Households that were engaged in farming in East Africa and other parts of the world faced challenges and changes in the first decade of 21st century in addition to increase in population that resulted into increased food prices, reduced fertility of soil and crop yields, poor access to markets, constrained access to land, and high inflation (Nelson *et al*.,2010). There is an expectation that up to 70% more food will have to be produced by 2050 to feed the growing populations especially in third world countries. However, Nuerfeldt *et al.,* (2011) explained that climate change will cause rise in temperature and change in precipitation patterns and the resultant weather extremes will negatively reduce global production of food.

In order to reduce and manage the risks of climate change, the farmers should use adaptation and mitigation strategies. According to the Victorian center for climate change adaptation research institute (2016), adaptation to climate change involves taking deliberate and considered actions that prevents, reduce or manage the effects of hotter, drier and extreme climate while taking the advantage of the opportunities which are brought by such changes. Climate mitigation involves actions that are taken to permanently eliminate or reduce the long-term risk and hazards of climate change to human life and property (GGW, 2016). According to United Nations Environment Program (UNEP), mitigation of climate change is simply the efforts that reduce or prevent greenhouse gasses emissions. If there will be substantial reductions in greenhouse gas emissions over the next few decades, then climate risks will reduce in the 21st century and beyond, which will subsequently increase prospects for effective adaptation, lower the challenges and costs of mitigation in long term and contribute pathways that are climate-resilient for sustainable development (IPCC, 2014). Climate change in IPCC refers to a change in the state of the climate that can be identified by changes in the mean and/or the availability of its properties and that persists for an extended period, typically decades or longer.

To examine the full range of climate change effects on agriculture, both biophysical and economic aspects should be considered and combined (Hillel and Rosenzweig, 2010). Climate change is leading to changes in global and regional climates which turn to have severe impacts on the growth of key crop such as maize as well as on socio-economic activities associated with agriculture and distribution of food (Waldmuller *et al*., 2013).

Modelling has played a very important role in improving efficiency of agricultural production systems in the last 30 years (Gettinby *et al.*, 2010). Decision Support System for Agrotechnology Transfer (DSSAT) was used in this study to project potential yields of maize under changing climate under different production scenarios. This model was used under rain fed conditions.

1.2 Problem statement

Climate change and variability is evident in Nyando Basin in western Kenya. There is an increase in droughts, floods and unpredictable rainfall which affect agriculture and food security (Macoloo *et al*., 2013). In the villages of Nyando, 81% of the families experience one to two months in a year with insufficient food, while 17% of the families experience three to four months in a year with insufficient food. In addition, during this period they are unable to produce crops from their farms due to drought (Kinyangi *et al.*, 2015). The primary source of income and food in Nyando is farming (mixed crop-livestock system), but the farmers have not diversified and show a few agricultural innovations (Macoloo *et al*., 2013). A household baseline survey that was carried out in Nyando by Mango *et al*.,(2011) observed that households that had not introduced any new crop were 37%, only one or two new crop varieties had been introduced by 32% and those households that had incorporated three or more new varieties of crops into their farming systems were 32% . There is scarcity of land in Nyando due to high population growth which results into small parcels of land per household. These parcels of land in some areas are severely degraded as a result of gully formation and depleted soils. Lack of proper land management practices by the farmers is also a leading cause in soil degradation. These challenges have direct negative effects on agricultural production in this area.

1.3 Justification of the study

Just like many Kenyan communities, Nyando communities have high preference for maize consumption. According to the survey report by Mango *et al.*, (2011), the number of households that cited maize as one of their most important crop were 99%, those that cited sorghum were 73% and beans were 35%. Climate changes will also influence the development of maize diseases, with increasing temperatures and incidents of drought susceptibility (Garrett *et* *al.*,2011) . Despite the climatic challenges facing maize production, maize consumption will continue to grow even if there are efforts to diversify to other food crops (Gitonga and Snipes, 2014). The 2014 long rains assessment report for Kenya estimated that 1.5 million people are acutely food insecure and will require immediate food assistance (KFSSG, 2014). This number has increased from 1.3 million who required food assistance in 2013, representing a 15% increase (KFSSG, 2014). This deficit in maize sufficiency coupled with high preference by farmers for maize consumption created a need to carry out the study on the effects of climate change and variability on maize yields under different climate scenarios as an adaptive approach.

1.4 Objectives

1.4.1 Broad objective

To use Decision Support System for Agrotechnology Transfer (DSSAT) CERES model to project maize yield responses to climate change and variability under different climate scenarios in the Lower Nyando region of Western Kenya.

1.4.2 Specific objectives

1. To asses maize yield responses to temperature and water variability over a projected period of 30 years using DSSAT Model
2. To determine the maize growth and yield responses to application of inorganic phosphorus and nitrogen fertilizer in Nyando

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Production of maize in Africa

Maize is produced globally and therefore, it is an important cereal crop that ranks third after rice and wheat (David, 1985). For the total world production, it is estimated that maize is grown on about 118 million hectares of which 19 million hectares are estimated to be in Africa (IITA, 1982). The major producers of maize are the United States, Brazil, France, India and Italy (Onasanya *et al*., 2009).

Maize became an important crop in Africa only after 1900 when different types were introduced by the Dutch in South Africa (Sanders, 1930). The most successful types, which eventually moved into East Africa, were Hickory King, White Horsetroth, Ladysmith White, Salisbury White, Champion white, Pearl and Iowa Silver Mine (Harrison, 1976). The local yellow maize in East Africa was derived from the early introductions of the Caribbean Flint and yellow dents from South Africa (IITA, 1982).

The first hybrid variety of maize to be introduced in Kenya was H611 in the year 1964 (Karanja, 1996). This variety was a cross between the improved Equadorian landrace (Equador 573) (Schroeder *et al.,* 2013). Its seeds were lower in costs compared to conventional hybrids and had lower yield loss when recycled (Smale and Jayne, 2003). These qualities prompted the development of hybrid maize in Kenya. Many hybrid maize varieties that are suitable for different agro-climatic zones are currently being released on yearly basis (Schroeder *et al*., 2013).

2.2 Suitable maize varieties for different agroecological zones

Maize production in Kenya is practiced in most agroecological zones (Schroeder *et al*., 2013).

A) Maize varieties for high altitude

They are suited to grow between medium to high altitude areas of 1500 to 2800 meters above sea level, with a daytime temperature of 28^{o}C and the night time temperature of 8^{o}C during the growing season (KSC, 2010). Examples of some varieties in this category are H627, H626, H625 and H614 (Schroeder *et al*., 2013). The rainfall requirements range between 800 to 1500mm.

B) Maize varieties for medium altitude

Medium altitude ranges between 800 to 1700 meters above sea level. Suitable maize varieties in this region include H511, H513, H515 and H516 (Schroeder *et al*., 2013). The rainfall measurement in these areas is between 750 to 1000mm and the maize mature within four to five months (KSC, 2010).

c) Transitional zone

This zone is found at altitudes of 800 to 2400 meters above sea level and the rainfall measurement of 1000 to 1800mm with temperatures of 12^{0}C to 30^{0}C (KSC, 2010). Some of the suitable maize varieties include H623 and H624 that have short, green-stems and takes around 150 days to mature (Schroeder *et al*., 2013). These varieties produce huge thick cobs and large dent kernels (KSC, 2010).

d) **Lowland agro-ecozone**

Maize varieties suitable in this zone include Pwani Hybrids (PH1 and PH4) that were released in 1987 (Schroeder *et al*., 2013). These varieties are fairly short, resistant to lodging and more tolerant to water stress. They grow at an altitude of 0-1250m above sea level with a minimum rainfall requirement of 400mm (KSC, 2010). They are suitable for intercropping, highly productive and capable of producing 16 bags of grain per hectare under good agronomic practices (Schroeder *et al*., 2013). They are uniform, short and tolerant to most leaf and ear diseases and mature within three to four months (KSC, 2010).

e) **Dryland transitional agro-ecozone**

The Katumani Composite B (KCB) is a short and fast growing open-pollinated variety and produces short cobs (KSC, 2010) This variety is drought escaping and matures within 90-120days (Schroeder *et al*., 2013). It performs well in altitudes of 500-1000m above sea level and is especially suitable for areas with marginal rainfall requirements of 250-500mm (KSC, 2010).

f) Dryland mid- altitude agro-ecozone

For this zone, recommended varieties are Dryland Composite 1 (DLC1) and Dryland Hybrid 1 (DH01) (Schroeder *et al*., 2013). These are open-pollinated varieties, good for semi-arid regions (altitude 1000-1900m) and are best suited to areas with short rainy seasons (minimum 350mm) (KSC, 2010) They are good substitutes for Katumani Composite B where rainfall is erratic and are commonly grown in the Eastern and Coastal regions of Kenya (Schroeder *et al*., 2013).They mature within three to four months and can produce 14 bags per acre. They are short, uniform and tolerant to most ear diseases (KSC, 2010).

2.3 Importance and uses of maize

Maize is used as food for human consumption, livestock feed and industrial raw material for many products.

I. Food for human consumption

The fresh maize grains are eaten roasted or boiled on the cob. The grains can be dried and cooked in combination with some edible leguminous crops like cowpea beans .They can also be milled and boiled as porridge with or without fermentation. They are regarded as breakfast cereal (Plessis, 2003) (Plessis, 2003). It can be baked into a form of bread (the famous unleavened bread) (Krenz, et al., 1999). Locally the dry grains can be popped. Each country has its special maize dish, whether it be ,as in Nigeria “Ogi” or "Akamu”, and “tuwo";in East Africa, "Ugali" and "Chenga” in Zaire and Zambia, "nshima and fufu" (IITA, 1982). It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Maize grains also have a great nutritional value as they contain 72 % starch, 10 % protein, 4.8% oil, 8.5 % fiber, 3.0 % sugar and 1.7 % ash (Chaudhry, 1983).

II. Feed for livestock

Generally the concentrates fed to livestock consists of grains with maize being the most important one in the tropics (IITA, 1982). The dry grains are milled and other ingredients added to make the mashes which vary in composition for the different classes of livestock. Maize forms 40-75 percent of the ration of these animals. The famers also strip off the green leaves from the maize stalk to provide fodder for their animals. Silage can also be made from maize before they reach full maturity (Krenz, et al., 1999). Dry stover from the mature plants after grain harvest is also used for ruminants feeding (Thorne, et al., 2002).

III. **Raw material**

Maize is number one agricultural raw material surpassing even wheat and rice (Rodgers, 2011). The industrial uses of maize may be divided into: fixed feed manufacture, dry milling, distillation and fermentation (IITA, 1982).The main products from the dry milling are grits, maize flour and breakfast cereals. Grits are coarsely ground endosperm of the kernel where germ and bran have been separated. Maize flakes are made by rolling grits after they have been flavored. The wet millers manufacture starch, feed, syrup, sugar, oil and dextrines. The fermentation and distillation industries mainly manufacture beers and other alcohol products.

2.4 Status of Maize Production in Kenya

In Kenya, maize is a staple crop. However, its production is dependent on rainfall (Wokabi, 2013). The national maize stocks as at the end of July 2014 stood at 0.9 million metric tons (KFSSG, 2014) as shown in Table 2.1.

Table 2: 1 Maize balance sheet (1st August 2014 to 31st October 2014)

Maize Balance Sheet through October 2014		**90 Kilograms bags**
Stock as at 31st July 2014 in 90kg bags		**9,844,558**
1	Total East Africa Imports expected between August to October 2014	1,800,000
2	Imports outside EAC between August 2014 to 31st October 2014	0
3	Estimated harvest between August 2014 to October 2014	5,500,000
Total available stocks between august and October 2014 (90kg bags)		**17,144,558**
1	Post-harvest losses estimated at 10%	1,714,456
2	Amount used to manufacture feeds and other industrial products (2% of stocks)	342,891
3	Amount used as seed(1% of household stocks)	163,000
4	Expected total exports to East Africa	0
5	Expected exports outside EAC region	0

Projected national availability as at 31st October 2014 (90 kg bags)		**14,924,211**
1	Consumption at 3.84 million bags/month for 43 million people for 3 months (august to 31st October ,2014)	11,520,000
2	Balances as at 31st October 2014 (surplus/deficit)	3,404,211
3	Surplus	3,404,211
4	Number of months available stock can last from the end of march 2014	Less than a month

Source: Ministry of Agriculture, Livestock and Fisheries, 2014

According to Wokabi (2013), majority of maize farmers do not apply fertilizers therefore, harvest yields of between 1.1 to 2.5 t ha^{-1}. The land sizes are continuously reducing and this will force the future production of maize to depend on technologies that enhance improved farming methods (Gittinger, 2008). Prediction shows that maize crop will become crop that is highly produced globally especially in developing world by 2025. Rosegrant *et al.* (2008) further explained that the demand for maize in developing world is expected to double by 2050.

The prices of maize in Kenya are among the highest in Sub-Saharan Africa and yet the average Kenyan consumes 98 kilograms of maize annually with its poorest quarter of the population spending 28% of its income on the crop (Jaetzold *et al*., 2008). The FAOSTAT (2013) report explained that maize value chain in Kenya suffers from constraints right from the input, production, marketing up to the final consumer and this can be rectified with the right technologies, policies and marketing innovations. In addition, appropriate research should be identified and carried out in order to facilitate continued high yields production while incorporating the short term and long term needs of the soil (Wokabi, 2013).

2.5 Climate Change: What is the Evidence?

Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and which persists for an extended period, typically decades or longer (Field *et al*., 2014). The Intergovernmental panel on climate change (IPCC) 2007 report showed that carbon dioxide concentrations are rising in the atmosphere with resultant increase in temperatures. The lower atmosphere and the upper layers of the ocean have warmed, snow and ice cover are decreasing in the Northern hemisphere, Greenland ice sheet is shrinking and the sea level is rising (Cicerone & Nurse, 2015) and this is coupled with extreme storms (Hansen *et al.*, 2015).In Africa, climate change is a reality. This is observed through intensified and prolonged droughts especially in East Africa, increased cases of unprecedented floods in West Africa, reduced rain forests in equatorial Africa and increase in ocean acidity in areas around South coast of Africa (Besada and Sewankambo, 2009). There is a concern reported by International Panel on Climate Change (IPCC) that Africa is not acting very fast in addressing the dire environmental and economic consequences of greenhouse gas emissions (IPCC, 2014). The Royal Society report (2010) on climate change explained that there is strong evidence that global warming is being caused by human activities such as burning fossil fuels and changes in agriculture and deforestation.

2.6 Impacts of climate change on agriculture

Agricultural production is directly affected by climate change (Adams, 2010). Negative effects of changes in climate on crop productivity are more compared to benefits based on studies that covered a wide variety of crops and different regions globally (Field *et al.,* 2014). Crops are very sensitive to changes in moisture, temperature and carbon dioxide (CO_2) (Adams, 2010). Negative climatic effects like heat waves, droughts and floods reduce the yield potential of crops (White *et al.*, 2014).

Herrero, *et al.* (2010) carried out a study on how production of maize in Kenya is impacted by climate change using methods described by Rosegrant *et al.* (2008) up to the year 2050. The projected results up to 2050 showed lower yields of maize in rain fed agriculture in four out of six scenarios with a reduction by 20% for the more semi-arid areas of Kenya (Thornton *et al.*, 2009).

Some of the climate change challenges on agriculture in the 21st century identified in Ngaira *et al*. (2007) include disruption and interference with natural ecosystem stability and adaptation by a warmer climate, such that desert ecosystems and grassland will expand in area while the rich forest ecosystems will reduce in area. The agriculture practiced in marginalized areas like arid and semi-arid lands (ASAL) will suffer most as these areas will be hotter therefore their natural ecosystem may not easily adapt to new harsh conditions. This may consequently result into extinction of ASAL ecosystem biodiversity especially crops that are not drought resistant. Ecological hazards of soil erosion, droughts and desertification may worsen making areas where they occur un-inhabitable in future. There will be rise in sea level that will cause coastal flooding due to a warmer climate. If the average temperature increases by between 1.5 to 4.5^0C, the scientists calculated that the ocean expansion could cause a rise in sea levels by between 20 to 140 cm. This scenario would adversely affect marine fishing especially pelagic fishing (fishing those species which live near the surface of the ocean like Dolphin, Banito, sail fish and Tunny). There will be adverse effects on water use and availability epecially in the tropics, negatively impacting large reservoirs and irrigation projects by making them to dry up.

The agricultural sector in Africa is likely to experience periods of prolonged droughts and/or floods during El-Nino events resulting into agriculture losses of between 2-7% of GDP by 2100 in parts of the Sahara, 2-4% & 0.4-1.3% in Western and Central Africa and Northern and Southern Africa respectively (FAO, 2009). Arid and semi-arid land could expand in coverage by 60-80M ha. According to overseas development institute (ODI) in 2008, productivity in Africa will be further undermined by a reduction in fertile agricultural land available and an expansion in the coverage of low potential land.

2.7 Future climate Projections

Weather is a primary determinant of agricultural production and weather data are needed for many different types of analysis in agricultural science (Jones and Thornton, 2013). A global climate model can produce projections of precipitation, temperature, pressure, cloud cover, humidity, and a host of other climate variables for a day, a month, or a year (White *et al.*, 2014).

2.7.1 MarKSIM climate generator

MarkSim climate generator is a third order Markov rainfall generator that was developed over 20 years ago for downscaling weather information by employing both climate typing and stochastic downscaling approaches (Jones and Thornton, 2013; Jones, 2003) (Jones, et al., 2003)

Marksim climate generator estimates maximum and minimum air temperatures and daily solar radiation values from monthly means of these variables using methods of Richardson (1981). The monthly solar radiation values are estimated from temperatures, longitude and latitude using the model of Donatelli and Campbell (1997). The climate record contains longitude and elevation of location, latitude, monthly values of rainfall, daily average temperature and daily average diurnal temperature variation.

2.7.2 Representative concentration pathways (RCPs)

There are four greenhouse gas concentration (not emissions) trajectories that were adopted by IPCC for its fifth Assessment Report (AR5) in 2014 (Moss *et al.*, 2008). These pathways are used for research in climate modeling because they describe four possible climate futures which are considered possible depending on how much greenhouse gasses are emitted in the years to come. The four RCPs are RCP2.6, RCP4.5, RCP6, and RCP8.5

These emission scenarios are used in climate research to explore how humans could contribute to future climate change given uncertainties in factors such as economic development, population growth and development of new technologies. The future projections and scenarios of social and environmental conditions are used to explore the impacts that climate change will have on different possible states of the world e.g. futures with lesser or greater amounts of poverty (Bjones, 2012). The aim of using scenarios is not to predict the future but explore both the scientific and real world implications of different plausible futures.

2.7.3 RCPs used in fifth assessment report (AR5)

1. **RCP-8.5, High emissions**

This RCP corresponds to a non-climate policy scenario that translates to severe climate change impacts and was developed in Australia by the International Institute for Applied System Analysis (Cubasch *et al.*, 2013). It is characterized by increasing greenhouse gas emissions which leads to high greenhouse gas concentrations over time. It is comparable to Special Report on Emission Scenarios (SRES) scenario A1 F1.

This future is characterized by CO_2 emission that will be three times in the year 2100 compared to today's, rapid increase in methane emissions, increased use of cropland and grassland that will be driven by increase in population, up to 12 billion world populations by 2100, low development, increased reliance on fossil fuels, high energy intensity and no implementation of climate policies.

2. **RCP 6, Intermediate emissions**

It was developed in Japan by National Institute for Environmental Studies in Japan. After 2100, radiative forcing will be stabilized which is consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions (Bjones, 2012). It is comparable to Special Report on Emission Scenarios (SRES) scenario B2

This future is characterized by over reliance on fossil fuels, energy intensity that is intermediate, declining use of grassland and increasing use of croplands, methane emissions that are stable, and emissions of CO_2 peak in 2060 at 75% above today's levels then decline to 25% above today.

3. **RCP 4.5, Intermediate emissions**

It was developed in the United States by the Pacific Northwest National Laboratory. Under this RCP, radiative forcing is stabilized shortly after 2100, consistent with a future with relatively ambitious emissions reductions (van Vuuren *et al.*, 2011). It is comparable to Special Report on Emission Scenarios (SRES) scenario B1

This future is characterized by energy intensity that is lower, reforestation programs that are strong, yield increases and dietary changes resulting into decreased use of croplands, climate policies that are stringent, methane emissions that are stable and emissions of CO_2 that increases slightly before decline commences around 2040

4. **RCP 2.6, Low emissions**

It was developed by Netherlands Environmental Assessment Agency. Radiative forcing reaches 3.1 W/m2 before it returns to 2.6 W/m2 by 2100. Greenhouse gas emission reductions would be required over time in order to reach such forcing levels (Bjones, 2012). This scenario does not have a comparable SRES scenario.

This future is characterized by reduced use of soil, energy intensity that is low, 9 billion world population by year 2100, bio-energy production resulting into increase in cropland use, animal husbandry that is more intensive, 40% reduction in methane emissions, emission of CO_2 stays at today's level until 2020 then reduces and becomes negative in 2100, and the concentration of CO_2 peak around 2050 followed by a modest decline to around 400 ppm by 2100.

2.7.4 Reliability of the models used to make projections of future climate change

The source of confidence in the ability of models to simulate important aspects of the current climate is by routinely and extensively assessing them by comparing their simulations with observations of the atmosphere, ocean, cryosphere and land surface (IPCC, 2007). Model evaluation has been done over the last decade through organized multi-model intercomparisons. These intercomparisons showed significant and increasing skills in representing many important mean climate features, such as the large-scale distributions of atmospheric temperature, precipitation, radiation and wind, and of oceanic temperatures, currents and sea ice cover (Randal and Wood, 2014).

Another source of confidence comes from the ability of models to reproduce features of past climates and climate changes (Moss, et al., 2008). Models have been used to simulate ancient climates, such as the warm mid-Holocene of 6,000 years ago or the last glacial maximum of

21,000 years ago (Randal and Wood, 2014). These models are able to reproduce many features (which allow for uncertainties in reconstructing past climates) such as the magnitude and broad-scale pattern of oceanic cooling during the last ice age.

Models are also able to simulate many observed aspects of climate change over the instrumental record. Example includes the global temperature trend over the past 19th century that can be modelled with high skill when both human and natural factors that influence climate are included (Randal & Wood, 2014).

The ability of models to represents these and other important climate features increases our confidence that they represent important physical processes that are essential for simulation of future climate change.

2.8 DSSAT Crop Model

Decision support system for Agrotechnology transfer (DSSAT) is a cropping model that simulates growth, development and yield of crops growing under described managements over time (Mukhtar & Fayyaz, 2011). This model was originally developed by an international network of scientists to facilitate application of crop models in a systems approach to agronomic research (Jones *et al.,* 2003).

The initial development of DSSAT crop model was motivated by a need to integrate knowledge about soil, climate, crops, and management for making better decisions about transferring production technology from one location to others where soils and climate differed (Uehara & Tsuji,1998; IBSNAT, 1993). It permits easy incorporation of diverse application packages because of well-defined and documented interface to modules (Mukhtar and Fayyaz, 2011) and helps decision makers by reducing the time and human resources required for analyzing complex alternative decisions (Tsuji *et al*., 1998). DSSAT is a collection of independent programs that operate together and crop simulation models are at its center (Jones *et al.*, 2003) as shown in Figure 2.1. Data bases describe weather, soil, experimental conditions and measurements, and genotype information for applying the models to different situations.

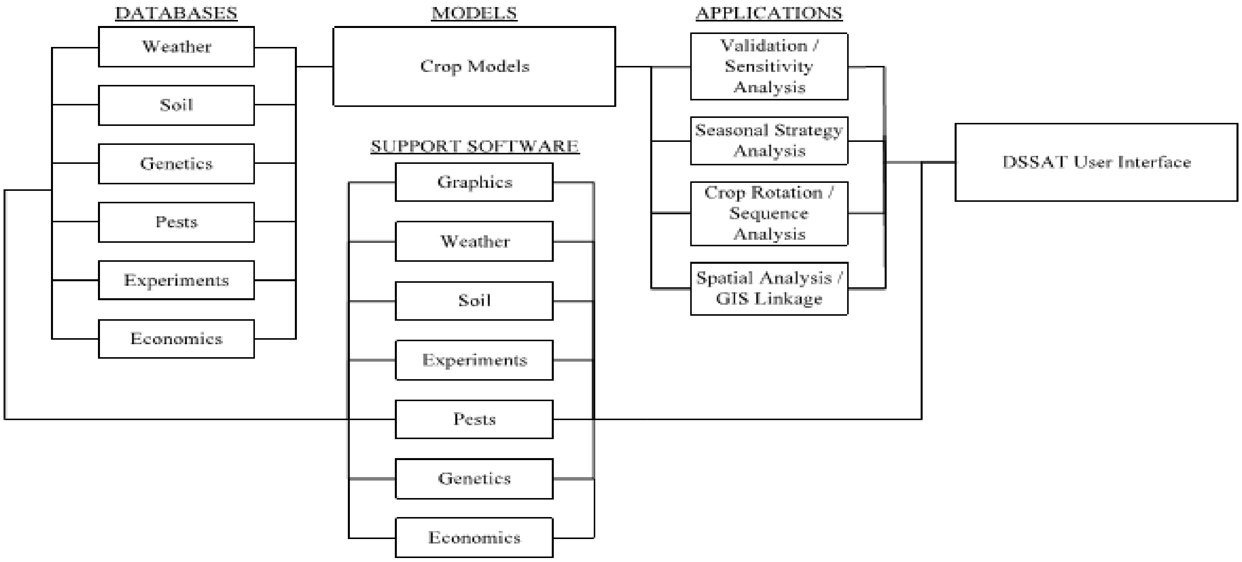


Figure 2. 1 Diagram of database, application and support software components and their use with crop models for applications in DSSAT

DSSAT uses application softwares which aid to prepare these databases and to compare simulated results with observed values so as to improve model's efficiency and accuracy (Mukhtar and Fayyaz, 2011).

2.8.1 DSSAT Data Requirement

The DSSAT model requires the minimum dataset for its operation (Jones *et al.,* 2003). The contents of the dataset were specified based in works of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and the International Consortium for

Agricultural Systems Applications (ICASA) (Hunt and Boote, 1998). They encompass data on the site where the model is to be operated, on the daily weather during the growing cycle, on the characteristics of the soil at the start of the growing cycle or crop sequence, and on the management of the crop (e.g. seeding rate, fertilizer applications, and irrigations).

The required weather data for DSSAT includes daily recorded solar radiation incident on the top of the crop canopy, rainfall, maximum and minimum air temperature. Further needed data include water holding characteristics of different soil layers, root weighing factor which accommodates the impact of several adverse soil factors on root growth in different soil layers like salinity, pH, and impedance. Other parameters that are needed include surface run off, drainage and evaporation from the soil surface (Ritchie, 1972). The initial values of nitrate, ammonium and soil water are needed as well as the estimate of the above and below ground residues from the previous crop. The crop management aspects that include modifications to the environment (e.g. photoperiod extension) as imposed in some crop physiology studies are needed. Crop management factors that include irrigation, planting date, planting depth, raw spacing, fertilization, inoculation and plant population are used. In some crops, plant bed configuration and bund height is necessary. Also, the DSSAT requires coefficients for the genotypes involved (Hunt, 1993; Ritchie, 1993)

2.8.2 Where DSSAT has worked

Musinguzi *et al.* (2014) used DSSAT-Century model in simulating the influence of management practices on soil carbon dynamics. He used long-term datasets from Kiboga-Uganda (1980-2010) and Kabete, Kenya (1976-1996). The model calibration and evaluation showed a good fit between simulated and observed values of soil organic carbon. The continuous tillage simulation with no fertilization for the antecedent period of 1980-2010 and extrapolated period of 2010-

2060 showed high rates of soil organic carbon declining in the newly cultivated soil compared to a degraded soil.

The simulated rate of decline was 849 kg ha $^{-1}$ yr^{-1} for the continuously cultivated soils and 2129 kg ha $^{-1}$ yr^{-1} for the newly cultivated soil. DSSAT-Century model confirmed that continuous use of tillage is a major threat to soil organic carbon building and restoration of soil fertility in the tropics.

Egeh (2004) did a study on surface soil and phosphorus transport using DSSAT model. He incorporated Modified Universal Soil Loss Equation and sediment-bound P model into CROPGRO-Soybean and CERES-Maize models. He collected data of sap flow from maize plants in a sheltered and unsheltered areas in a field near Iowa and Ogden. He incorporated erosion and sediment bound P subroutines into CERES-Maize and CROPGRO-Soybean models. After calibrating them, he tested them using five years of data collected from the two field sites.

The results showed that both models over and under-predicted daily sediment and sediment bound P losses from fields but seasonal values were simulated very well. In CERES model, the simulated and measured seasonal sediment losses error was less than 10% in three out of the five years, while the difference between simulated and measured sediment was less than 15% in four out of the five years in CROPGRO. The study concluded that even though both models did not seem to give good estimates of phosphorus and daily sediment losses, they can still be used to simulate long term losses with reasonable accuracy.

Ting Li *et al.* (2015) simulated long term spring wheat yields, soil organic carbon, nitrogen and water dynamics using DSSAT-CSM in a semi-arid region of the Canadian prairies. He evaluated the overall performance of DSSAT-CSM for simulating wheat yield, grain nitrogen uptake, soil organic nitrogen, soil organic carbon, soil water and nitrate dynamics. Long-term (1967-2005) data was used from spring wheat experiment conducted at Swift Current, Saskatchewan in the semi-arid Canadian prairies. DSSAT-CSM successfully simulated soil water and NO_3-N dynamics in 0 to 15 m depth but overestimated in soil water and NO_3-N in deep layers and consequently underestimated NO_3-N leaching therefore suggesting further improvements in the soil water module to be done for the semi-arid climatic conditions in Canadian prairies.

Atakora,*et al.* (2014) used DSSAT to model maize production towards site specific fertilizer recommendation in Ghana. DSSAT model was calibrated using various crop growth and development data observed at the field experiment at Kpalesawgu. Obatanpa maize variety was used in the experiment. After validation the results showed good agreement between predicted and measured yields with a NRMSE value of 0.181. Generally, the maize yield simulations under Guinea savanna agro-ecological conditions were good as the average predicted yields were close to the measured values with MD of 336.0, RMSE of 498.77, NRSME of 0.181 and simulated and observed mean yields of 3096 and 2750 kg ha^{-1} for the entire treatments respectively. DSSAT model appeared to be suitable for the Guinea savanna agro-ecological conditions in Ghana based on these simulated results.

2.8.3 Advantages and limitations of DSSAT

Advantages of DSSAT

DSSAT simulates both physiological effects of CO_2 and various crop management practices. Apart from simulating the effects of climate change on crop production, DSSAT can evaluate various management practices and genotypes found under climate change scenarios. It also offers operational simplicity because it is user friendly with pop-up menus and can handle long-term simulations. Lastly, it can simulate sequence cropping of more than one crop and also study the long-term effects on soil organic matter and related issues due to particular combination of cropping systems.

Limitations of DSSAT

DSSAT model is not able to capture and simulate all the crops grown in the whole world. It is not able to correctly predict responses to extreme weather events such as weeds, insect pests and diseases. Lastly, DSSAT is not programmed to simulate intercropping systems which is very common in smallholder farms in sub Saharan Africa.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Study area

The Lower Nyando block where the study was carried out is located in the plains of Lake Victoria in Nyando and Kericho sub-counties (Figure 3.1). It is within a 10 km by 10 km block known as the Lower Nyando Block, (Between 0^{o}13'30''S - 0^{o}24'0''S, 34^{o}54'0''E – 35^{o}4'30''E)

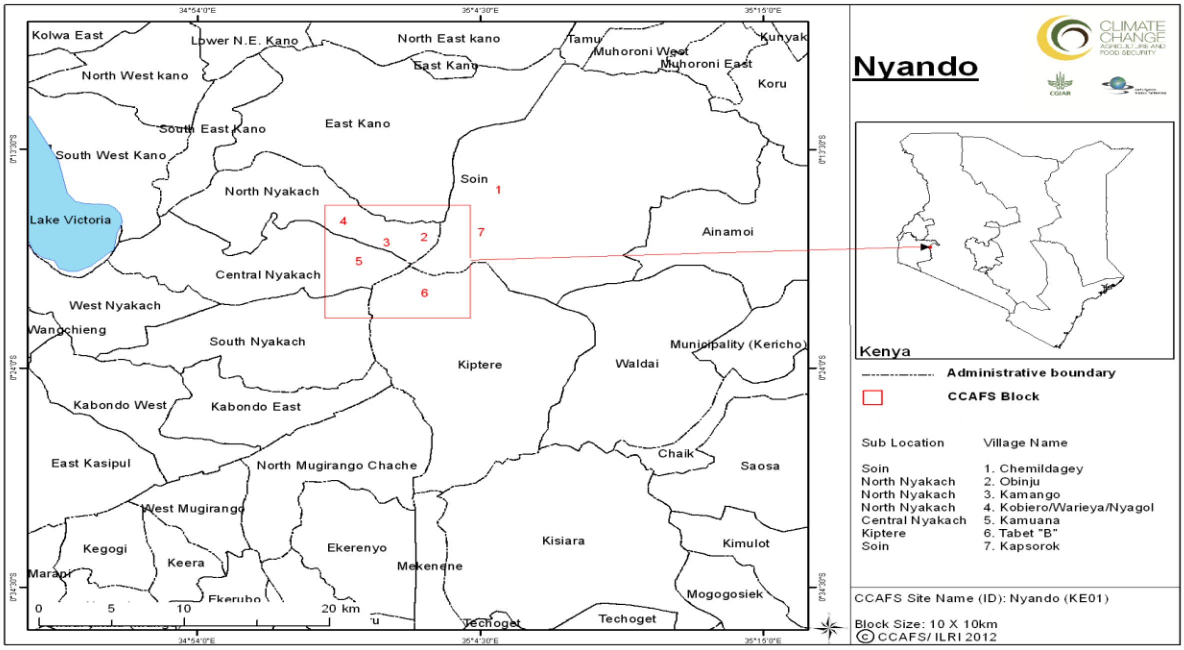


Figure 3. 1 Location of the study area.

*Source: Climate Change Agriculture and Food Security Site Atlas, Nyando/KatukuOdeyo, Kenya (*Sijmons *et al*., 2013*)*

The total population of the area is about 750,000 people, mainly living in the Nyando and Kericho sub counties. The population is mainly Luo and Kalenjin. The high human population density has consequently resulted in sub-division into small farms (less than 1 ha). The area is largely used for subsistence agriculture, consisting of mixed cropping systems. Main crops are maize, sorghum and sugarcane as the main cash crop.

3.2 Climate of the study site

The region experiences bi-modal rainfall. The first season is experienced throughout the whole region from March to May (Verchot *et al.,* 2007). The second season differs slightly depending on the location, but usually occurs in September/October (Onyango *et al.,* 2005). During the second season, the average annual rainfall ranges between 450mm and 600mm. Generally, the mean annual rainfall in Kisumu is 1,280 mm (County Govt, 2013). Temperatures remain relatively stable throughout the year, although average annual temperatures change spatially depending on the altitude. Average annual maximum temperature is between 25^0C to 35^0C and the minimum temperature is between 9^0C to 18^0C (County Govt, 2013).

3.3 The soils

Soils in Lower Nyando include Luvisols, Vertisols (locally known as Black Cotton soils), Planosols and Cambisols (FAO-UNESCO,1988) which frequently occur in saline or sodic phases with deep profiles of moderate to low fertility (Cohen *et al.,* 2006) dominate the area. In the highland part of Nyando, Kericho sub county side, predominant soil types (FAO-UNESCO, 1988) include Ferralsols, Nitisols, Cambisols and Acrisols, and are generally structurally stable (Cohen *et al.,* 2006).

3.4 Land use and vegetation

The landscape of the lower Nyando block is dominated by farm and grazing land (52%) and perennial grassland (34%) as indicated in Table 3.1.

Table 3. 1 Land cover classification

Vegetation strata	**Percentage**
Farm land	21
Forage land	31
Perennial grassland	34
Shrubland	4
Woody bush/grass land	7
Heavily degraded/hard setting	3

Source: World Agroforestry Centre 2013

3.5 Data collection

The data collection procedure included primary data that was collected by administering questionnaire to 70 respondents. In addition, secondary data was also used, and was collected through reviewing existing literature during problem description and assessment of Nyando sub county experiences in maize production.

3.5.1 Population

This research focused on the small holder farmers in Kisumu County, Nyando district. A total of 70 farmers were interviewed in the area. These represented the majority population in the area which is affected both directly and indirectly by climate change. The sample (n = 70) was balanced between men and women (50%). The age range of the sample was from 18 to 60. It’s a probability sample that incorporates simple random sampling technique where every member of the population has a known and equal chance of being selected.

3.5.2 Research Design

This study used purpose sampling technique in selecting subjects for study. According to Marshall, (1996), a researcher actively selects the most productive sample to answer the research questions so that reliable information that can be used to make valid judgements regarding the phenomena under study is obtained. Therefore, I selectively selected farmers who showed a distinction and capability in carrying out activities that I required. These activities included planting of maize crops, planting dates, Maize varieties being planted, correct spacing, application of manure or fertilizer, tillage practices and harvest.

3.6 Assessment of maize yield responses using DSSAT CERES maize model

This study was conducted to project the future yields of maize under different scenarios for small-scale farmers. The results aimed at helping in decision making in maize variety selection, inspire more research to address the future probable reductions in yields for certain varieties and set up the right adaptive measures that will counter the future simulated variation in climate and resultant yields. Using DSSAT CERES Maize Model, three varieties that were common among farmers in Nyando were selected and simulated. They include Katumani Composite B as early maturing maize variety, hybrid H511 as middle maturing maize variety and hybrid H614 as the late maturing maize variety.

Table 3. 2 Summary of climate, soil and maize management data that was collected

Data type	**Source of data**	**Collection method**	**Analysis**
Climate data			
Rainfall Radiation Maximum temperature Minimum temperature	Meteorological substation station in Kisumu	Collected from Kisumu meteorological weather station	Fed into WeatherMan utility in DSSAT model
Soil data			
Total Nitrogen Phosphorus pH Moisture content Organic carbon Soil texture Bulk density Exchangeable cations	Farms in Nyando before planting of maize	Soil sampling in 5 farms, 2 samples per farm	Laboratory chemical and physical analysis. The results were entered into SBuild soil utility of DSSAT
Crop management practices			

Tillage Seed varieties Spacing Planting date Fertilizer application Harvest date Yields	Farms in Nyando during the 2015 long rain growing season for maize	Administering Questionnaires to 70 farmers.	Used SPSS to analyze the questionnaires. The management results were exported into XBuild utility of DSSAT

3.7 Soil physical and chemical analysis

Soil physical analysis that were carried out include particle size distribution that was done using Hydrometer methods described by Ashworth *et al.* (2001), soil bulk density determined by Core method (Prickner, *et al.,* 2004) and volumetric moisture content determined by multiplication of moisture content by the bulk density.

The soil pH was determined using the general procedure for soil PH (2: 5: 1 H_2O) .Soil Organic Carbon Organic carbon was determined by the modified Walkley and Black procedure outlined by Nelson and Sommers (1982). Total N was determined by the Micro-Kjeldahl method (Tel and Hegatey, 1984). The available phosphorus was determined using Malik method (1988). Exchangeable cations were analyzed using excess of 1M NH_4OAc (Ammonium acetate) (Chapman, 1965).

3.8 Agronomic data

Agronomic data was collected through administration of questionnaires, observation and crop growth measurement. The data collected include planting dates, spacing, tillage, plant height at physiological maturity (maturity was determined when the silk appeared to be dried and the eye of the grain appeared dark), number of days to 50% silking, number of days to 50% tasseling, plant height at harvest measured from the base of the plant to the flag leaf and yields harvested.

3.9 Model Inputs

3.9.1 Weather

The following weather data were used in the model: rainfall, maximum temperature, minimum temperature and solar radiation. This data was obtained from Kisumu meteorological station.

To assess the impact of climate change under different climate scenarios on maize production, climate data was generated from MarkSim DSSAT weather file generator, a MarkSim web version for IPCC AR5 data in the Coupled Model Intercomparison Project Phase 5 (CMIP5).This data was downscaled using three different GCMs, CSIRO-Mk3-6-0, HadGEM2-ES and MIROC-ESM, under Representative Concentration Pathways 4.5 and 8.5 for the years 2030 and 2050. RCP 4.5 is the most consistent with future development in Kenya, where improvements in energy structure and new low-emission technologies that limit emissions are most likely to be legislated. Projections from the RCP 8.5 scenario imply the absence of climate policies therefore it was necessary for comparison.

3.9.2 Creating the weather file

The Weatherman utility in DSSAT was used to create the weather file for DSSAT CERES Maize Model. The data I used to create the weather file include station information: name of weather station, latitude, longitude and altitude. Daily maximum and minimum temperature, daily solar radiation and daily rainfall for a period of fifty four years (1960-2014) were imported into the DSSAT model. Their units of measurements were converted into those used by the DSSAT. The data was then edited and exported to DSSAT ready for use by the CERES-Maize model.

3.9.3 Soil Data

The DSSAT-CERES used a simple, one dimensional soil-water balance model developed by Ritchie (1985). The following soil data was collected from the soil in Nyando: bulk density, soil texture, pH (water), organic carbon, total N, and available P. Descriptive data that were used include slope, drainage, runoff and relative humidity.

3.9.4 Converting soil information into DSSAT model soil profile input

Soil data tool (SBuild) under the tools section in DSSAT v 4.6 was used to create the soil database which was used for the general simulation purposes. Name of the country, name of study site, site coordinates, soil series and classification were among the data entered in this utility. Soil chemical properties that were entered included percent total N, available P (mg kg^{-1}), CEC (cmol kg-1) and pH. Percent clay, silt and gravel entered in the SBuild utility was used to calculate hydraulic conductivity, saturated upper limit and drained upper limit.

CHAPTER FOUR

4. RESULTS

4.1 CLIMATIC CONDITIONS

4.1.1 Trends in annual rainfall distribution from 1960 to 2014

The available long-term historical climate data from Kenya Meteorological Department (KMD), Kisumu station was analyzed to characterize the variability and trends in historical climatic conditions. In general, the annual rainfall in Nyando showed high temporal variability with a coefficient of variation of 25% shown in Figure 4.1.

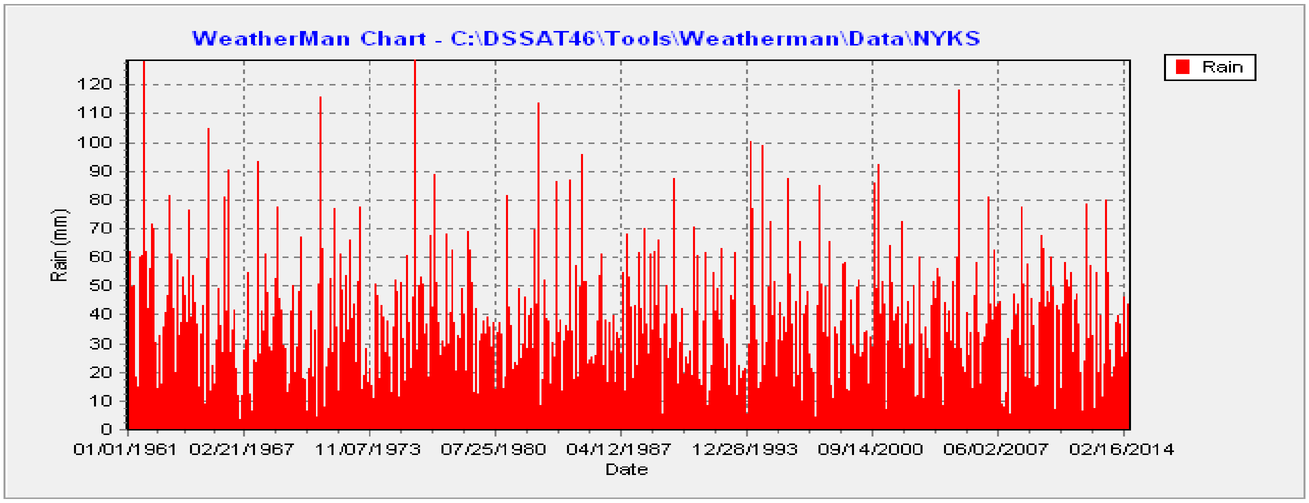


Figure 4. 1 Rainfall distribution in Nyando from 1960 to 2015

The years between 1981 to1990 experienced a drastic variation in annual rainfall received with a coefficient of variation of 39.3% compared to the period from 2001 to 2010 which had a coefficient of variation of 23.5%. The average rainfall for the period of 2001 to 2010 was 524.42mm which was higher than the period of 1981 to 1990 that had an average of 444.55 mm.

The year 2014 recorded the lowest average annual rainfall with a total of 345 mm since the year 2000

4.1.2 Trends in temperature for the past 50 years

Temperature records in Figure 4.2 shows a slight variation in the average trend over the years.

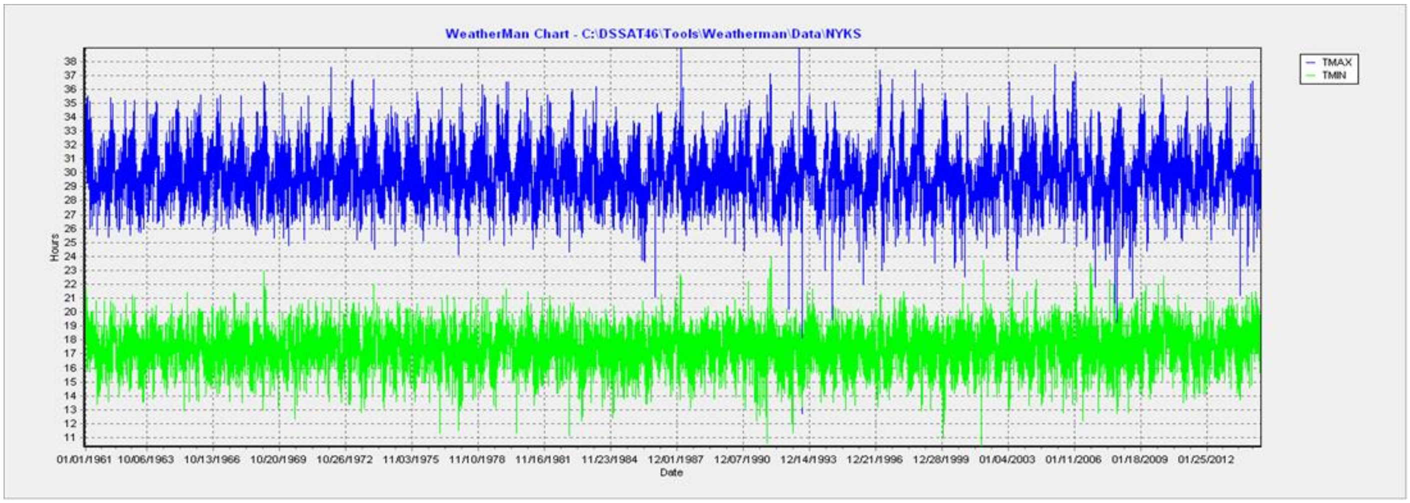


Figure 4. 2 Historical variation in minimum and maximum temperatures in Nyando.

The average annual temperatures were increasing at the rate of 0.011^{0}C every year. Minimum temperatures were getting warmer by 0.005^{0}C every year while the annual increase in maximum temperatures was 0.007^{0}C. When analyzed for decadal wise increase, the average annual temperature in Nyando during the period 2001-2010 was 0.067^{0}C higher compared to the period 1981-1990, an indicator of rise in temperatures.

4.1.3 Projected climate for 2030 and 2050

The models projected maximum temperatures of up to 40^0C in the months of February, October and November in both 2030 and 2050 as shown in Figures 4.3 and 4.4.The months with lowest maximum temperatures were April, July and August recording temperatures of less than 25^0C.

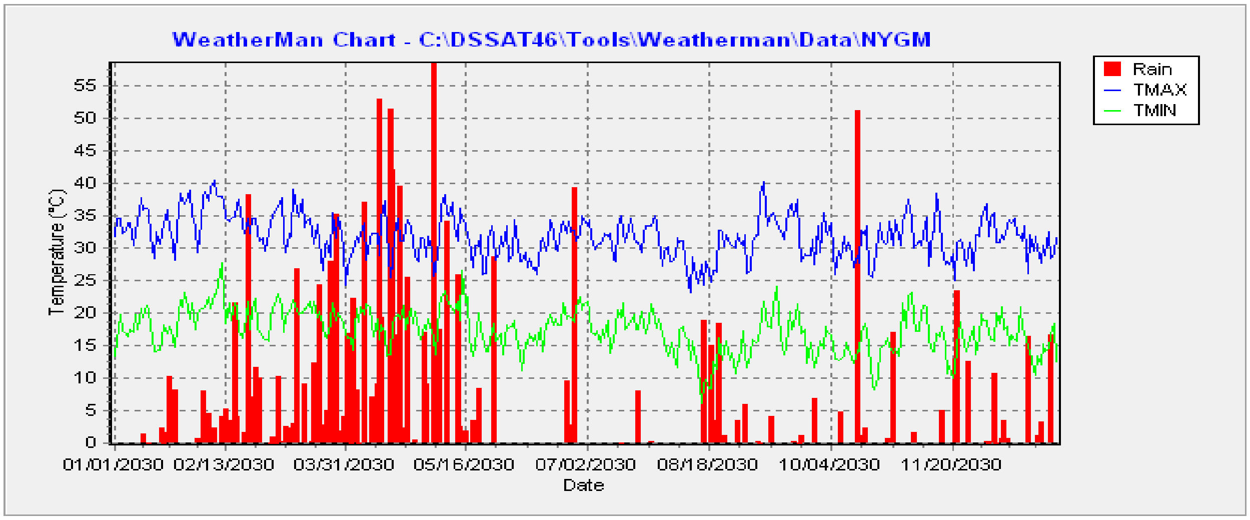


Figure 4. 3 Projected climate in Nyando for 2030

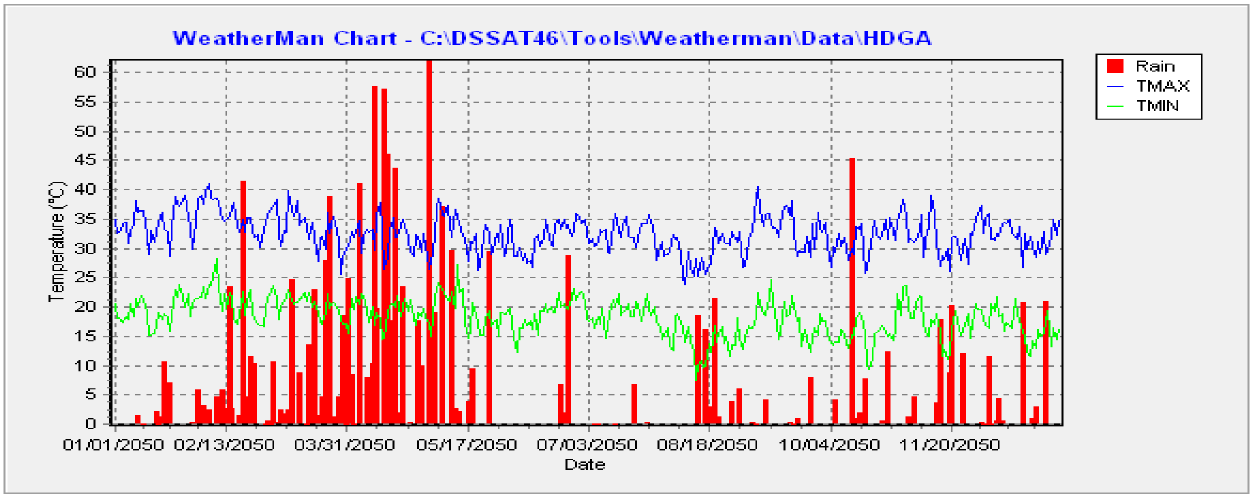


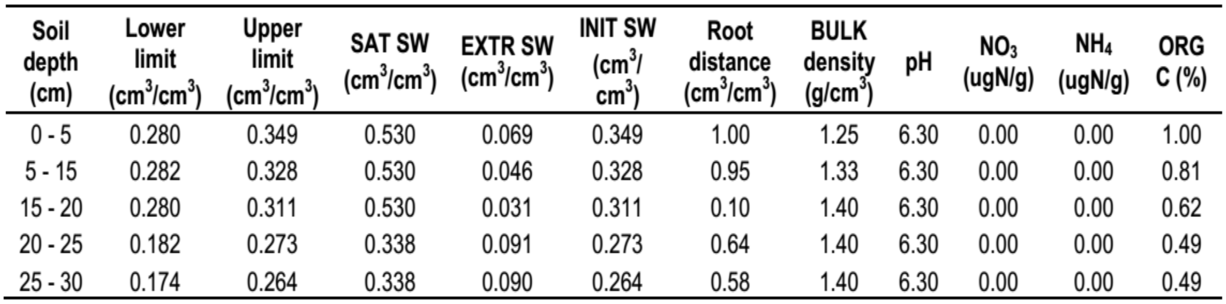
Figure 4. 4 Projected climate in Nyando for 2050

The projected minimum temperatures were lowest in the month of August recording below 10^0C both in the years 2030 and 2050. However, by 2050 the annual minimum temperatures will increase by 7.14%.

4.2 Soil and crop growth parameters

The collected and analyzed soil data was input into the SBuild utility of DSSAT and used in the simulation. Table 4.1 shows a summary of the soil input parameters in the SBuild utility of DSSAT model.

Table 4. 1 Summary of DSSAT soil parameters



Soil depth (cm)	Lower limit (cm^3/cm^3)	Upper limit (cm^3/cm^3)	SAT SW (cm^3/cm^3)	EXTR SW (cm^3/cm^3)	INIT SW (cm^3/cm^3)	Root distance (cm^3/cm^3)	BULK density (g/cm^3)	pH	NO_3 (ugN/g)	NH_4 (ugN/g)	ORG C (%)
0 - 5	0.280	0.349	0.530	0.069	0.349	1.00	1.25	6.30	0.00	0.00	1.00
5 - 15	0.282	0.328	0.530	0.046	0.328	0.95	1.33	6.30	0.00	0.00	0.81
15 - 20	0.280	0.311	0.530	0.031	0.311	0.10	1.40	6.30	0.00	0.00	0.62
20 - 25	0.182	0.273	0.338	0.091	0.273	0.64	1.40	6.30	0.00	0.00	0.49
25 - 30	0.174	0.264	0.338	0.090	0.264	0.58	1.40	6.30	0.00	0.00	0.49

SAT SW, saturated water content; INIT SW, initial soil water; ORG C, Soil organic carbon

The top layer of soil from 0 to 5 cm depth which is the main rooting depth for the maize fibrous roots had a bulk density of 1.25 g cm^{-3} and from 15 to 30 cm had 1.4 g cm^{-3}. The soil organic carbon from 0 to 5 cm deep also had 1.00% with saturated water content of 0.53 cm^3 cm^{-3}.

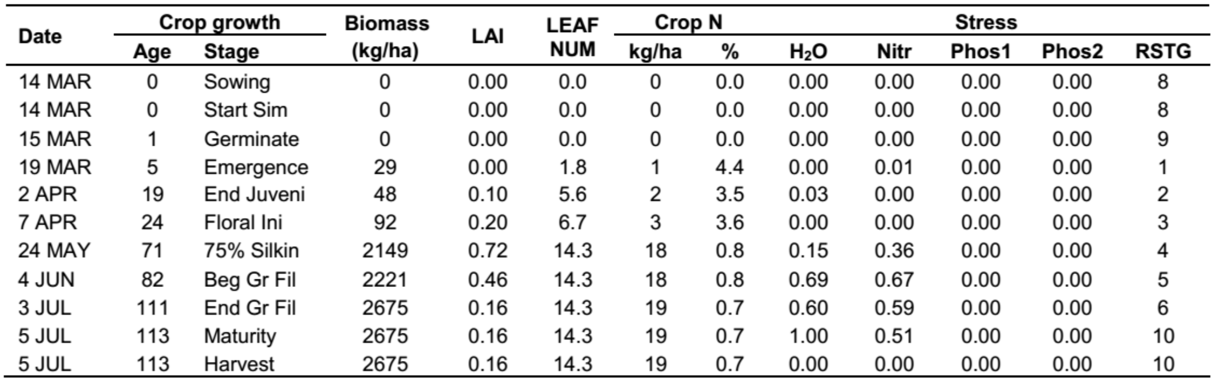
4.3 Sensitivity analysis of DSSAT-CERES

This was done using Katumani Comp B, Hybrid 511 and Hybrid 614 as low, middle and high altitude maize varieties respectively. The sensitivity analysis was done whereby each maize variety growth parameters were adjusted respectively to suit Nyando’s climatic and crop growth conditions. The input parameters that were sensitive in this study were fertilizer application (both nitrogen and phosphorus fertilizers) and the growing periods for the three maize varieties. During the sensitivity analysis, the fertilizer input and the maize varieties growing periods were adjusted accordingly. This was done to determine how sensitive the output of the model was to changes in the input parameters. It was done in order to understand the behavior of the model whereby whenever a small change in an input parameter resulted in relatively large changes in output, then the model was considered to be sensitive to that parameter.

4.4 Model evaluation

DSSAT-CERES model was evaluated using data collection from a total of 70 farmers in Nyando during long rain season of 2015.The row spacing that was used by farmers for the three maize variety was 75 cm, planting date of 14th march 2015, application of 50 kg ha^{-1} of di-ammonium phosphate fertilizer during planting and 50 kg ha^{-1} urea fertilizer during top dressing. The growth to maturity for Katumani Comp B was 113 days, H511 was 125 days and H614 was 184 days. The results for model evaluation are shown in Tables 4.2, 4.3 and 4.4 for the three maize varieties.

Table 4. 2 Simulated crop and soil fertility status at main development stages for Katumani Comp B in Nyando



Date	Crop growth		Biomass (kg/ha)	LAI	LEAF NUM	Crop N		Stress				
	Age	Stage				kg/ha	%	H_2O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
2 APR	19	End Juveni	48	0.10	5.6	2	3.5	0.03	0.00	0.00	0.00	2
7 APR	24	Floral Ini	92	0.20	6.7	3	3.6	0.00	0.00	0.00	0.00	3
24 MAY	71	75% Silkin	2149	0.72	14.3	18	0.8	0.15	0.36	0.00	0.00	4
4 JUN	82	Beg Gr Fil	2221	0.46	14.3	18	0.8	0.69	0.67	0.00	0.00	5
3 JUL	111	End Gr Fil	2675	0.16	14.3	19	0.7	0.60	0.59	0.00	0.00	6
5 JUL	113	Maturity	2675	0.16	14.3	19	0.7	1.00	0.51	0.00	0.00	10
5 JUL	113	Harvest	2675	0.16	14.3	19	0.7	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, Leaf number; CROP N, Crop nitrogen

Table 4. 3 Simulated crop and soil fertility status at main development stages for H511in Nyando

Date	Crop growth		Biomass	LAI	LEAF NUM	Crop N		Stress				
	Age	Stage	(kg/ha)			kg/ha	%	H_2O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
7 APR	24	End Juveni	86	0.19	6.7	3	3.7	0.02	0.00	0.00	0.00	2
12 APR	29	Floral Ini	152	0.31	7.8	5	3.6	0.00	0.00	0.00	0.00	3
4 JUN	82	75% Silkin	2198	0.54	16.6	18	0.8	0.28	0.49	0.00	0.00	4
15 JUN	93	Beg Gr Fil	2437	0.37	16.6	19	0.8	0.15	0.70	0.00	0.00	5
6 JUL	114	End Gr Fil	2583	0.15	16.6	19	0.7	0.91	0.55	0.00	0.00	6
8 JUL	116	Maturity	2583	0.15	16.6	19	0.7	1.00	0.39	0.00	0.00	10
17 JUL	125	Harvest	2583	0.15	16.6	19	0.7	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, Leaf number; CROP N, Crop nitrogen

Table 4. 4 Simulated crop and soil fertility status at main development stages for H614

Date	Crop growth		Biomass	LAI	LEAF NUM	Crop N		Stress				
	Age	Stage	(kg/ha)			kg/ha	%	H_2O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
7 MAY	49	End Juveni	143	0.30	7.8	5	3.7	0.02	0.00	0.00	0.00	2
27 MAY	74	Floral Ini	244	0.47	8.9	9	3.6	0.00	0.00	0.00	0.00	3
28 JUL	135	75% Silkin	2343	0.51	18.8	19	0.8	0.29	0.55	0.00	0.00	4
2 AUG	140	Beg Gr Fil	2276	0.32	18.8	19	0.8	0.86	0.72	0.00	0.00	5
5 SEP	174	End Gr Fil	2299	0.20	18.8	19	0.8	0.98	0.56	0.00	0.00	6
7 SEP	176	Maturity	2299	0.20	18.8	19	0.8	1.00	0.07	0.00	0.00	10
15 SEP	184	Harvest	2299	0.20	18.8	19	0.8	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, Leaf number; CROP N, Crop nitrogen

4.5 Comparison of 2015 observed and simulated yields in Nyando

DSSAT-CERES simulated yields for 2015 showed high performance of Katumani Comp B variety which gave average yields of 2675 kg ha^{-1} as shown in Figure 4.12 compared to the observed of 2597 kg ha^{-1}.

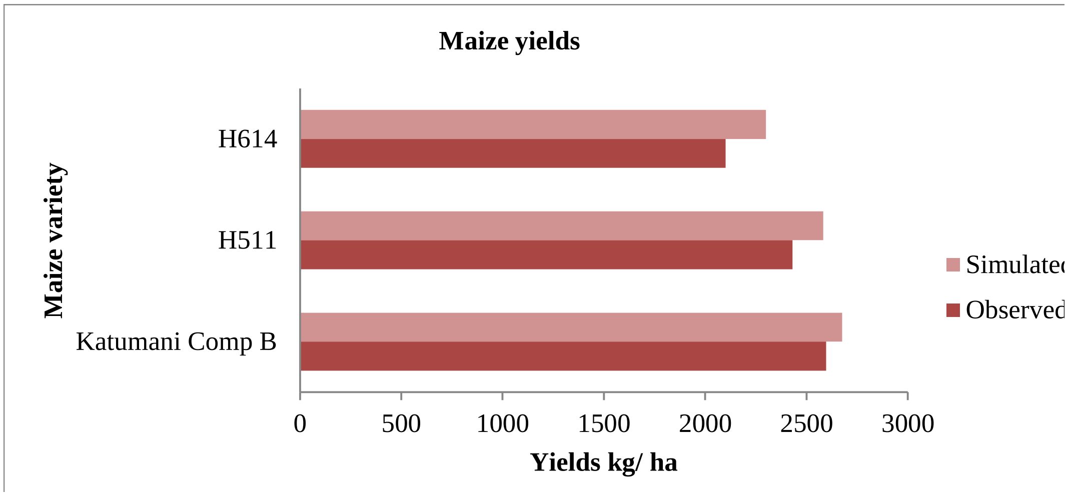


Figure 4. 5 Maize simulated yields for the year 2015

DSSAT-CERES simulated yields for H511 maize variety were 2583 kg ha^{-1}. This variety is most suited in medium altitude agro-ecological zones of 1000 to 1800 meters above sea level and takes between 100 to 150days to maturity and harvesting.

As for H614, DSSAT-CERES simulated yields of 2299 kg ha^{-1}. H614 variety is recommended for medium to high altitudes (1500-2100m) where day temperatures seldom exceed 28^{0}C during growing season and the night temperatures drop to as low as 8^{0}C. Rainfall requirements range from 800-1500mm (KSC, 2010).

4.6 Projected maize yields for the years 2030 and 2050 in Nyando using DSSAT CERES model

4.6.1 Projected maize yields for the year 2030

Figure 4.6 shows projected yields under representative concentration pathway 4.5. The projected results indicates best yields for Katumani Comp B across the three GCMs with the highest yields of 2369 kg ha^{-1} under HadGEM and low yields of 1889 kg ha^{-1} under MIROC-ESM. H511 also performed better than H614 maize variety across the three GCMs

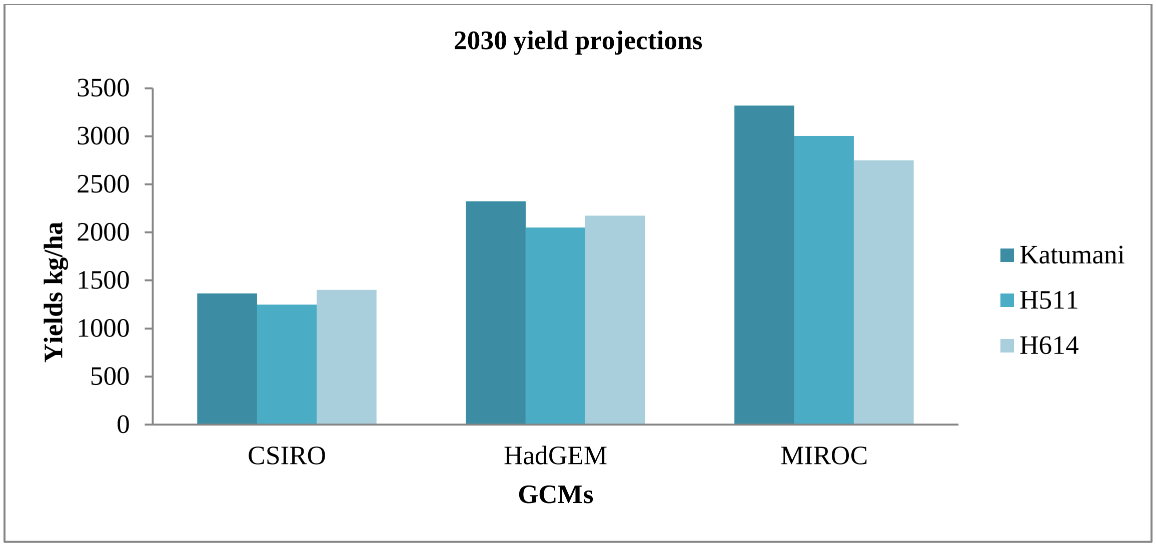


Figure 4. 6 The yield projections in DSSAT-CERES for 2030 under RCP 4.5

The simulated yields for H511 were highest under HadGEM at 2068 kg ha^{-1}and lowest by 1661 kg ha^{-1} under MIROC-ESM. H614 also performed better under HadGEM with yields of 2200 kg ha^{-1} and low yields by 1579 kg ha^{-1} under MIROC –ESM.

Projection of yields was also done under representative concentration pathway 8.5 for the year 2030. The result in Figure 4.7 showed better yields for Katumani Comp B across the three GCMs with yields of 3319 kg ha^{-1} under MIROC-ESM.

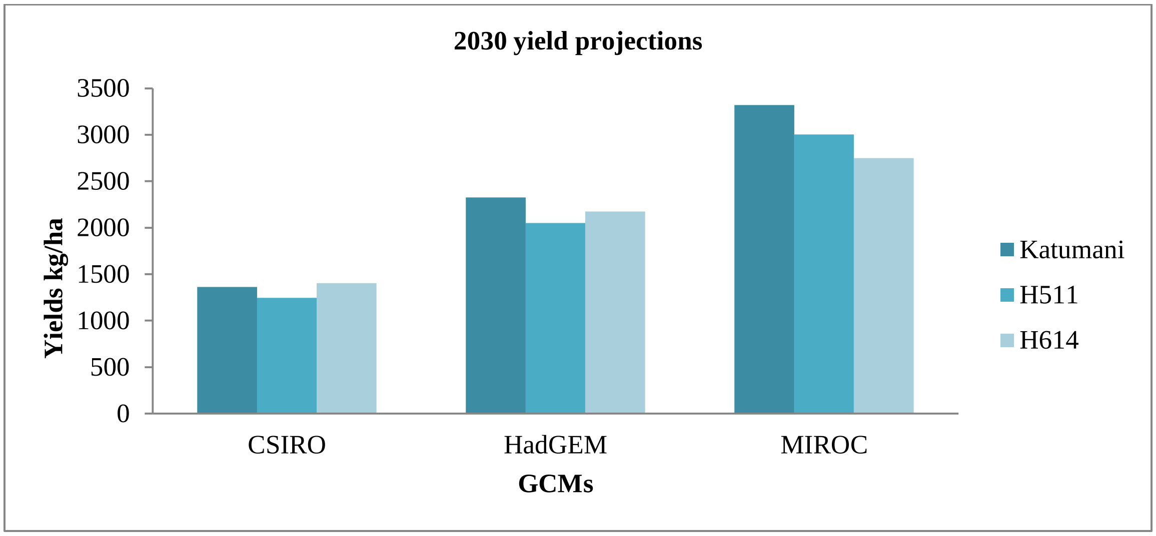


Figure 4. 7 The yield projections in DSSAT-CERES for 2030 under RCP 8.5

H511 and H614 also performed well under MIROC-ESM with 3003 kg ha^{-1} and 2750 kg ha^{-1} respectively. The lowest projected yields in RCP 8.5 were for H511 under CSIRO with the projected yields of 1247 kg ha^{-1}.

4.6.2 Projected maize yields for the year 2050

The 2050 yield projections under representative concentration pathway 4.5 are shown in Figure 4.8. Higher yields projections were of Katumani Comp B with 3142 kg ha^{-1} followed by H511 with 3085 kg ha^{-1} under MIROC-ESM. The overall yields projections for Katumani Comp B were higher across the three GCMs.

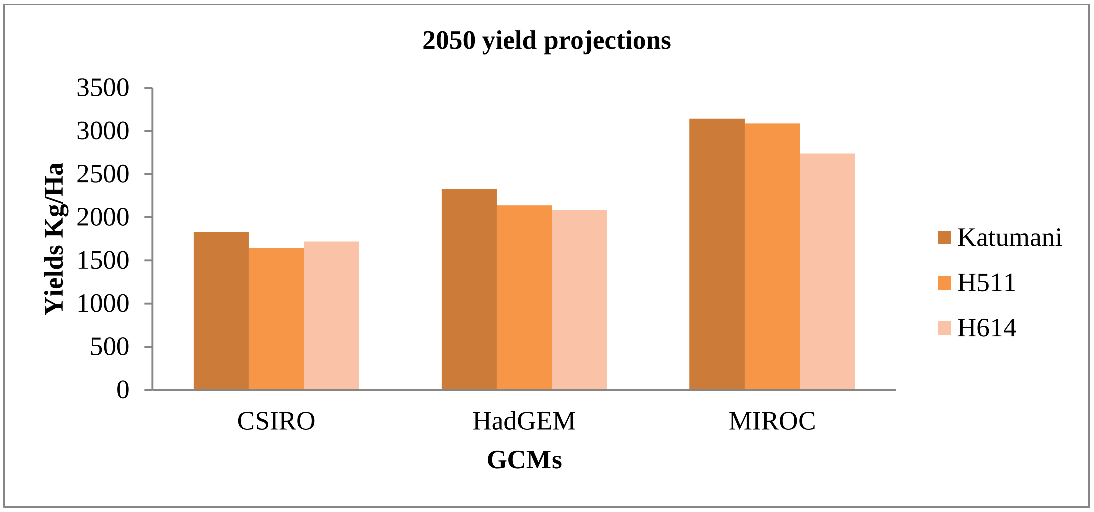


Figure 4. 8 The yield projections in DSSAT-CERES for the year 2050 under RCP 4

The lowest projected yields were for H511 with 1643 kg ha^{-1} under CSIRO. Projections under representative concentration pathway 8.5 in Figure 4.9 had lower yields across the three GCMs compared to RCP 4.5.

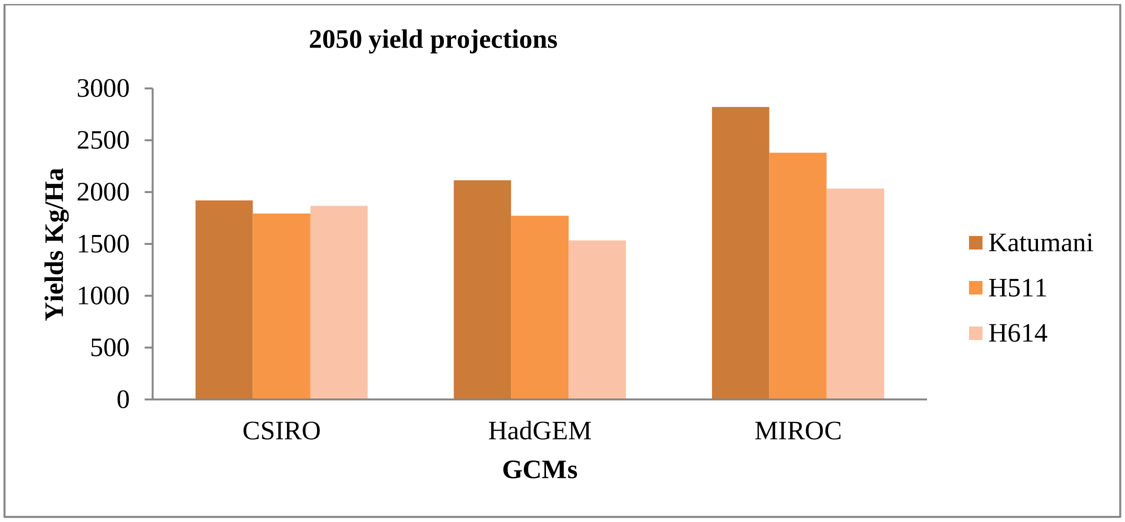


Figure 4. 9 The yield projections in DSSAT-CERES for the year 2050 under RCP 8.5

The highest projected yields were of Katumani Comp B with 2819 kg ha^{-1} followed by H511 with 2378 kg ha^{-1} and lastly H614 with 2034 kg ha^{-1} under MIROC-ESM. Average projected yields for H511 and H614 across the three GCMs were 1928 kg ha^{-1} and 1811 kg ha^{-1} .The lowest projected yields were for H614 with 1534 kg ha^{-1}.

4.7 Effects of nitrogen and phosphate fertilizer application on maize yields as an adaptation measure

4.7.1 Projected yields under RCP 4.5 and 8.5 without nitrogen and phosphate fertilizer application for the year 2030

The highest projected yield without nitrogen (N) and phosphorus (P) fertilizer application under representative concentration pathway 4.5 for the year 2030 was from H614 at 1403 kg ha^{-1} under CSIRO (Figure 4.10). This was followed by Katumani Comp B at 1364 kg ha^{-1} and H511 by 1247 kg ha^{-1} under the same CSIRO.

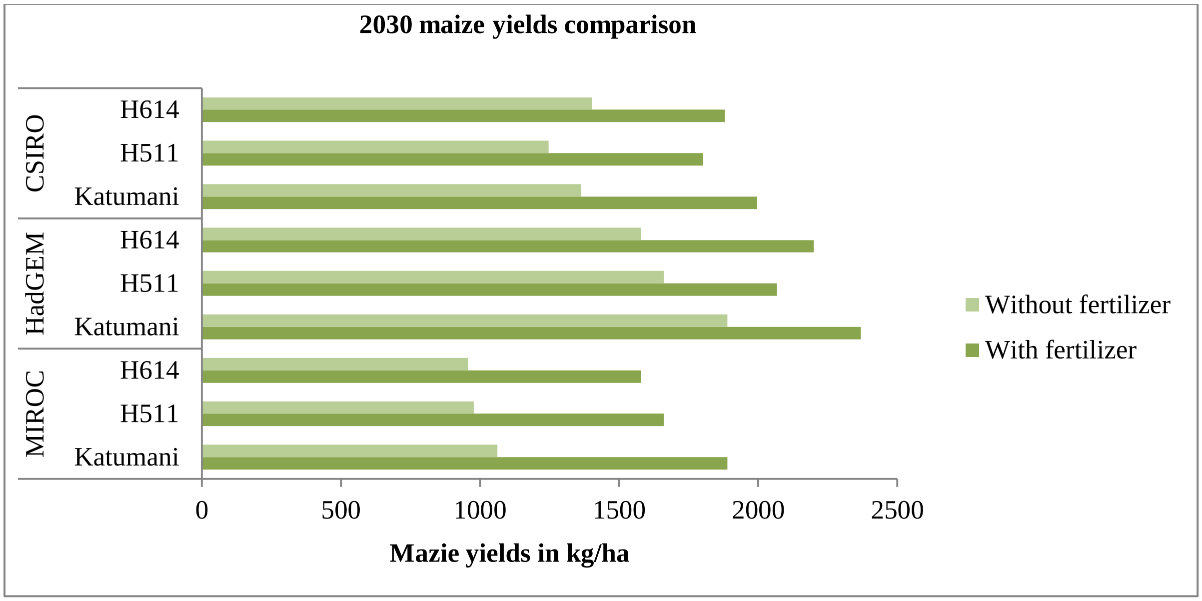


Figure 4. 10 Comparison of maize yields with and without nitrogen and phosphate fertilizer application for the year 2030, under RCP 4.5

The lowest projected yields for the year 2030 without application of phosphate and nitrogen fertilizer were 957 kg ha^{-1} from H614 under MIROC-ESM. H511 and Katumani Comp B also projected low yields of 978 and 1063 kg ha^{-1} respectively under MIROC-ESM. Quantitatively, the highest percentage of reduction in yields due to lack of N and P application for the year 2030 under RCP 4.5 will be 44 % for Katumani Comp B. H511 projections also showed yield reduction by 41 % under MIROC-ESM. The lowest projected yield loss was 25 % in H614 under CSIRO.

The projected yields for 2030 without N and P application under representative concentration pathway 8.5 (Figure 4.11) shows higher yields for Katumani Comp B with 1424 kg ha^{-1} under MIROC-ESM.

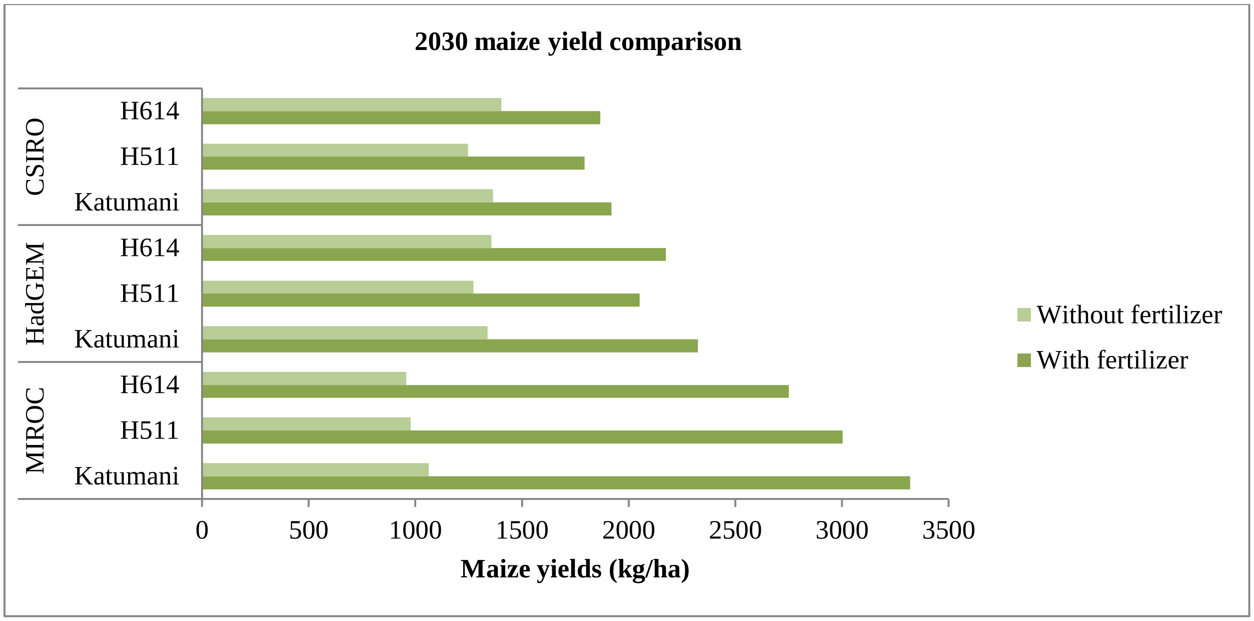


Figure 4. 11 Comparison of maize yields with and without nitrogen and phophate fertilizer application for the year 2030, under RCP 8.5

The lowest projected yield was 1242 kg ha^{-1} for H614 in MIROC-ESM. A Comparison between farmers who will apply fertilizer and those who will not showed yield reduction of up to 57 % in Katumani Comp B under MIROC-ESM. The projected yield reduction for H511 and H614 were also very high with 55 and 54% respectively under MIROC-ESM. The lowest projected percentage in yield reduction was in Katumani Comp B at 24.8% under CSIRO.

4.7.2 Projected yields under RCP 4.5 and 8.5 without nitrogen and phosphate fertilizer application for the year 2050

The projections of yields without N and P application for the year 2050 are shown in Figure 4.12 under representative concentration pathway 4.5. The results showed that the highest yields will be released from Katumani Comp B with 1432 kg ha^{-1} under MIROC-ESM. Projected yields for H511 maize variety under the same GCM were 1381 kg ha^{-1} while H614 were 1356 kg ha^{-1} under HadGEM.

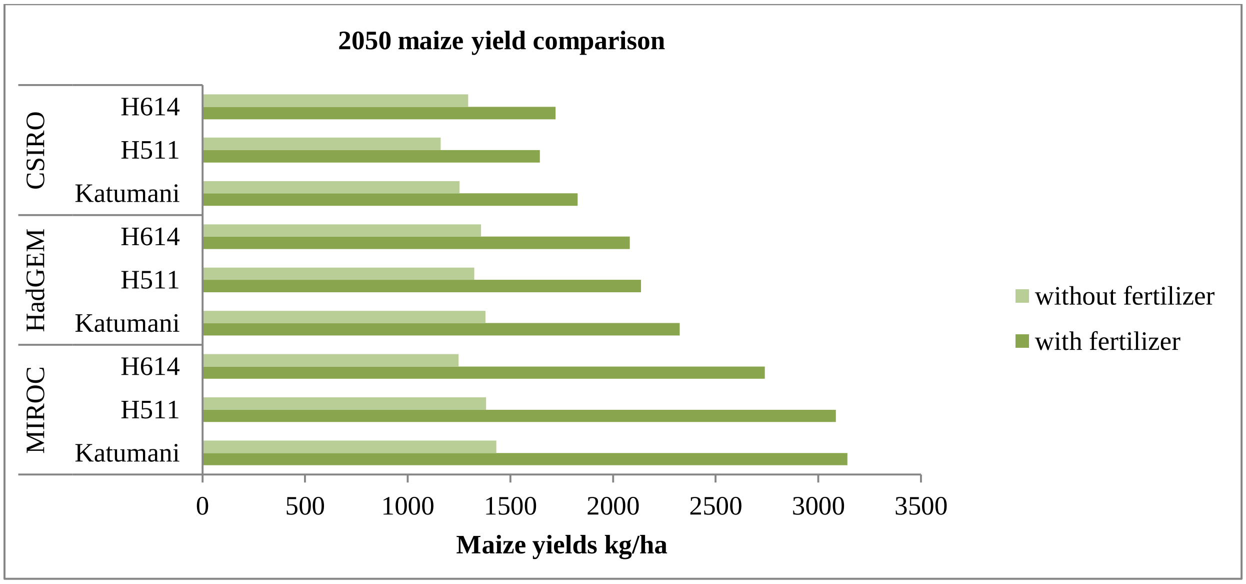


Figure 4. 12 Comparison of maize yields with and without fertilizer application for the year 2050, under RCP 4.5

The projected percentage reduction in yields between the farmers who will apply the N and P fertilizer and those who will not showed 55, 54 and 54% reduction for H511, H614 and Katumani Comp B respectively.

The maize yields projections without fertilizer application under representative concentration pathway 8.5 shows that H614 will give the highest yields of 1404 kg ha^{-1} closely followed by Katumani Comp B with 1394 kg ha^{-1}(Figure 4. 13).

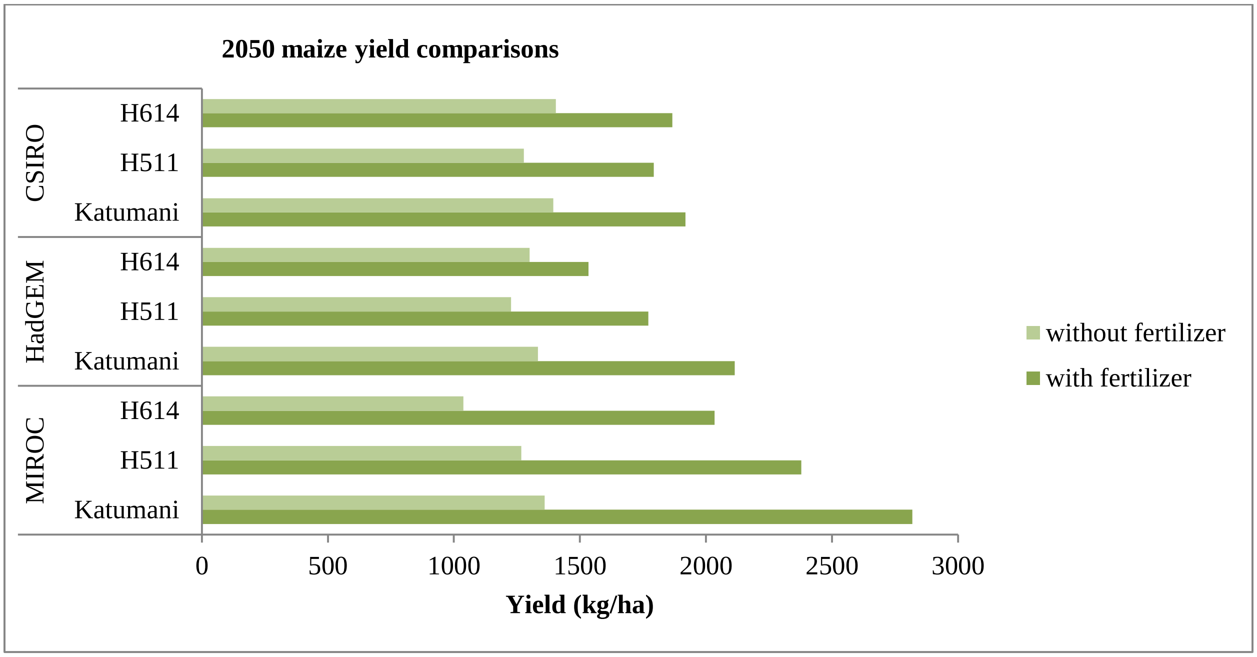


Figure 4. 13 Comparison of maize yields under N and P fertilizer application and without application for the year 2050, under RCP 8.5

The lowest projected yields for the year 2050 without N and P fertilizer application will be 1038 kg ha^{-1} by H614 under MIROC-ESM. The percentage reduction in yields due to lack of fertilizer application will be up to 52% in Katumani Comp B. H511 and H614 under MIROC-ESM also projected a high percentage in yield reduction by 47 and 49% respectively.

CHAPTER FIVE

5. DISCUSION

5.1 Trends in temperatures and precipitation

Trends in temperature from 1960 to 2014 for Nyando (Figure 4.2) showed a gradual increase in minimum and maximum temperatures that has increased by 0.011^0C and 0.007^0C. This finding is strengthened by the findings of Bassi *et al*. (2011) and McSweeney *et al*. (2003) who found out that the mean annual temperature has increased by 1.0^0C since 1960, at an average rate of 0.21^0C per decade. Cairns *et al.* (2013) found out an increase in number of days that are hot in Kenya to by 57 between the periods of 1960 to 2003. In addition Cairns *et al.* (2013) predicted that there will be increase in both maximum and minimum temperatures with a greater increase seen in maximum temperatures. Slingo and Chris (2003) explained that there has been widespread warming observed over Kenya since 1960 and the main causes being extreme events linked to the rainfall cycles and anthropogenic causes. The actual observed temperature trends are also consistent with the IPCC temperature projections (Christensen *et al*., 2007; IPCC, 2007).

Trends in annual precipitation indicate a decreasing trend in annual rainfall in Nyando (Figure 4.1). USAID (2010) report on climate trend analysis in Kenya indicated a decrease in historical annual rainfall in some parts of Kenya including western Kenya. William and Funk, (2010) also found out the same trend. The report by USAID (2010) explained that the decreases in rainfall were accompanied by significant increases in average air temperatures. Nyando rainfall ranges between 412 mm to 757 mm with a coefficient of variation of 39% from 2001 to 2014. These results were almost similar to the work of Herrero *et al.* (2010) where they found out that there is great variability in rainfall totals in Kenya. According to Bassi *et al.* (2011), climate change has affected rainfall by altering the rain duration and intensity.

5.2 Projected climatic conditions in the year 2030 and 2050

The 2015 annual maximum temperatures were at 29^0C (Figure 4.2). However, all the three GCMs projected an increase in temperature for the years 2030 by 2^0C under RCP 4.5 and 2.4 ^{0}C under RCP 8.5 (Figure 4.3). In 2050, the temperature will increase by 2.8 and 3.7^0C under RCP 4.5 and RCP 8.5 respectively (Figure 4.4). These observations are similar to those reported in the work of Rao *et al*., (2015). Similar work by the Agricultural Modeling Intercomparison and Improvement project (AgMIP) used 20 GCMs and found out that the median values for projected increase in maximum temperature to mid and end of 20th century periods are 1.6^0C and 1.8^0C under RCP 4.5 and 1.9^0C and 3.7^0C under RCP 8.5 (AgMIP, 2015). Bassi *et al*. (2011) projected a rise in the annual temperature to range between 1^0C and 5^0C, specifically 1^0C by 2020s and 4^0C by 2100.

The Intergovernmental Panel on Climate Change (IPCC) stated that, compared to the 1961-1990, the mean annual temperature will rise by between 0.8 - 0.9 ^{0}C across Kenya by the year 2030 and from 1.5 to 1.6 ^{0}C by the year 2050, while annual precipitation will change from 7.0 - 9.7 % and 13.3 - 18.8 % for 2030 and 2050 respectively (ICPAC and SEI, 2009). However, this study found out higher rise in temperatures in Nyando as compared to the general report in IPCC report by ICPAC and SEI (2009). The difference in results might be due bulk of data used and difference in GCMs used for climate projections. These trends in rainfall reductions and expected increase temperatures depicts uncertainty on rainfall reliability for future agricultural production in Nyando with potential increases in annual runoff masking overall reductions in water availability for crop production (Slingo and Chris, 2003).

5.3 Observed and simulated yields for 2015

In figure 4.5 Katumani Comp B performed better compared to H511 and H614 in both observed and simulated yields. It is a fast growing variety therefore capable of escaping drought by flowering within 60-65 days, maturing within 90-120 days and only requires 250-500 mm of rain which is characteristic rain in Nyando (KSC, 2010). H511 and H614 maize varieties are less suitable in this area due to their optimal required climatic conditions that are not available in Nyando. H511 and H614 require rainfall of between 750 to 1000mm and 800 to 1500 mm respectively (Schroeder *et al*., 2013) while Nyando has a rainfall range of between 450mm and 600mm (County Govt, 2013). Therefore, H511 and H614 experienced moisture stress which impacted negatively on their growth and productivity.

There was simulated stress in maize growth due to nitrogen and water deficiencies at 75% silking stage in all the three maize varieties (Tables 4.2, 4.3 and 4.4). This stage is vital in the growth stage because it determines the size of the comb and grain formation (Benedicta, *et al.*, 2012). Phosphorus deficiency was not experienced because most farmers applied superphosphate fertilizer during planting. Some farmers had applied farm yard manure during farm preparation thereby providing an additional source of phosphorus. The stress due to nitrogen deficiency at 75% silking stage implied that most farmers did not carry out top dressing using nitrogen fertilizer. Also Katumani Comp B maize variety experienced water stress at this stage because of low rainfall of 98.8 mm in June and 45.5 mm in July 2015 with no irrigation taking place.

5.4 Projected maize yields for 2030 and 2050

The baseline 2015 observed and simulated yields (Figure 4.5) for the three maize varieties are higher compared to the years 2030 and 2050 (Figures 4.6, 4.7, 4.8 and 4.9). High temperatures at the silking stage or tasseling result in significant decreases in yield (Southworth *et al.*, 2000). In addition, the projected yields for the year 2050 are lower than 2030. The decrease in yields in all the GCMs under both RCPs may be attributed to increase in temperatures and the slight changes in projected rainfall which appears to create non conducive environment for maize growth especially for H614 and H511 which are not tolerant to heat and water stress. In addition, these yields slightly vary under the three GCMs for both climate scenarios 4.5 and 8.5. This could be due to the effect of projected increase in temperature among the three GCMs (Appendix 2 and 3) where the maximum temperatures will increase up to 32^0C in 2030 and 33^0C in 2050 from 29^0C in 2015.Studies have shown that increased temperatures and changes in rainfall patterns will negatively affect major staple cereal food crops such as maize, sorghum and millet (Zinyengere *et al*.,2013) Analyses by Lobell *et al.* (2011) showed that each degree day spent above 30^0C reduced maize grain yield by 1% under optimal rain-fed conditions and by 1.7% under drought conditions in Africa. In addition, Benedicta *et al.* (2012) further explains that this difference in maize yields under the different climate scenarios is attributed to the amount and distribution of rainfall. In Bulgaria, Alexandrov and Hoogenboom (2000) investigated the effects of climate change on maize and found out that maize yields could be reduced by between 5% and 10% by 2050. This author deduced that the reason for reduction in yields is due to reduced growing period.

Herrero, *et al.* (2010) studied the impacts of climate change on maize crop production in Kenya up to 2050 and found out that the projected impacts of climate change to 2050 results in lower rain fed maize yield for Kenya in 4 out of 6 scenarios. Lobella *et al.* (2011) associates this reduction in maize yields to increasing maximum (day) temperatures that have a greater negative impact on yields than the minimum (night) temperatures. This increase in day temperatures/warming exacerbates evaporation and crop water deficits while the rainfall is declining (USAID, 2010)

The projected yield loss in Figures 4.18 and 4.20 for the year 2030 and Figures 4.22 and 4.24 for the year 2050 among farmers who will and will not apply fertilizer showed high percentage in yield difference. Lack of fertilizer application will result into a high loss in yields whereby Katumani Comp B, H511 and H614 will have reduced yields up to 57.1, 55.4 and 54.8% respectively under MIROC-ESM. According to FAO, (2000) expected continual yield and production of maize during the next 30 years will likely require increases in the use of fertilizers. Alexandratos and Bruinsma (2012) explained that nutrients budget in the soil vary over time. They further explained that higher yields are achievable through reduction of nutrient losses within cropping systems, which can be done through increased use of fertilizer. Therefore, maize yields under changing climate will rely heavily on the application of mineral fertilizers (Benedicta *et al.*,2012) This puts lots of emphasis on application of fertilizer among farmers in Nyando.

The results of this study indicate that Katumani Comp B maize variety will still remain the most productive and the most reliable maize variety compared to H511 and H614 maize varieties. In addition, the DSSAT-CERES maize model was able to give results that were almost similar to the maize growing pattern in Nyando hence satisfactorily simulated and projected the yields.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The changes in climate create uncertainties in the agricultural sector raising concerns on food and nutritional security. Some farmers in Nyando have not yet changed their farming systems by failure to use fertilizer as well as carrying out sustainable soil and water management practices. This will negatively impact them in terms of food production and security. DSSAT-CERES projections to 2030 and 2050 showed up to 50% reduction in yields for such farmers. On the other hand, DSSAT-CERES projections under the three global coupled models (GCMs) has shown that Katumani Comp B maize variety will still remain the most suitable variety to be grown in Nyando up to the year 2050 compared to H511 and H614. In addition, the moisture stress due to high evaporation as a result of increase in daytime temperatures will require that farmers practice early planting, select more resilient and drought tolerant maize varieties and also start practicing irrigation.

6.2 Recommendations

This study indicated that due to the projected changes in climate in Nyando, it is important to prepare mitigation measures that will ensure sustainable maize production in this area. This study proposes the adaptation measures that include (1) increase awareness of farmers to the possible impacts of climate change, especially the vulnerability of maize crops to these impacts and the relevant mitigation measures. Empowering farmers in the issues of climate change and its effects on the production of maize and other staple crops will also let them understand the interventions that are required to shield themselves against the inevitable impacts of these changes (2) look for alternatives to rain fed maize production in Nyando, including introduction of irrigation, run off harvesting and use of soil conditioners.

The DSSAT-CERES maize model was effective enough in simulation and projection of future maize yields in Nyando. I recommend the use of this model for future research with other crop types in Nyando under rain fed conditions and also to be tested under irrigated farming systems.

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APPENDICES

Appendix 1: Data collection questionnaire

UNIVERSITY OF NAIROBI

ADAPTING NYANDO SMALLHOLDER FARMING SYSTEMS TO CLIMATE CHANGE AND VARIABILITY THROUGH MODELLING

TOBIAS OKANDO RECHA

Introduction

I am Tobias Okando Recha, a master Student doing Land and Water Management in the department of Land Resource Management and Agricultural Technology (LARMAT) of the University of Nairobi.

I am undertaking a research on **Adapting Nyando Smallholder Farming Systems to Climate Change and Variability through Modeling**.

This work will is useful in assessing the impact of climate variability on maize production in this area and therefore, it will further help to improve maize yield in this county and our country, Kenya.

This questionnaire is designed to facilitate the assessment of the current situation of maize farming in Nyando.

Declaration

The information collected by this questionnaire is meant for research only and can be used as basis for further research on maize production in Kenya. To enable an accurate assessment, it is important that all information requested in the questionnaire is provided as completely and accurately as possible.

Name of Respondent

………………………… ………………………… ……………………………………

Occupation

………………………… ………………………. ……………………………………

Gender ………………… ….…………….

Date …… /……… /…………

1. How long have you stayed in Kisumu/Kericho County?

………………………………………………………………………………………………

2. At what extent do you produce maize? (Tick as appropriate)

   a. large scale (   )
   b. small scale (   )

3. When did you plant maize?

………………… ………………… …………………………………………………………

Why did you plant at that date?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

4. Which variety of maize have you planted?

………………… ………………… ………………………………………………………..

Why do you prefer this variety?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

5. Do you carry out soil tests before planting? Tick as appropriate.
Yes (   )   No (   )

If yes, which nutrients are soils tested for?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

6. Do you practice intercropping?
Yes (   )   No (   )

If yes state crops planted with maize.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

7. Which type of starter fertilizer do you use?

………………… ………………… …………………………………………………………..

Why do you prefer this type of fertilizer?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

8. How many seasons is maize production carried out in a year?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

9. Are there established planting dates for maize?
Yes (   )   No (   )

If yes, how do farmers establish the planting dates?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

10. To what depth do you sow?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

11. Do you practice top dressing? If yes state type and amount of fertilizer applied.

…………………………………………………………………………………………………

……………………………………………………………………………………………….

12. What spacing do you use when planting maize?

…………………………………………………………………………………………………

……………………………………………………………………………………………….

13. Which soil and water management practices do you apply for maize?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

14. Do you weed? How, when and how often?

…………………………………………………………………………………………………

……………………………………………………………………………………………….

15. What challenges do you face in the maize production process?

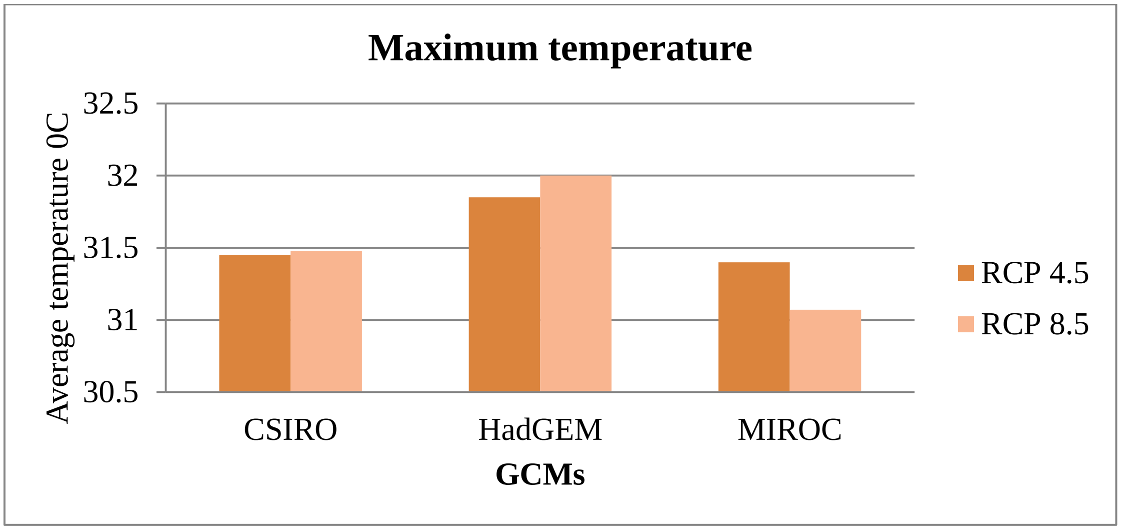
…………………………………………………………………………………………………

………………………………………………………………………………………………..

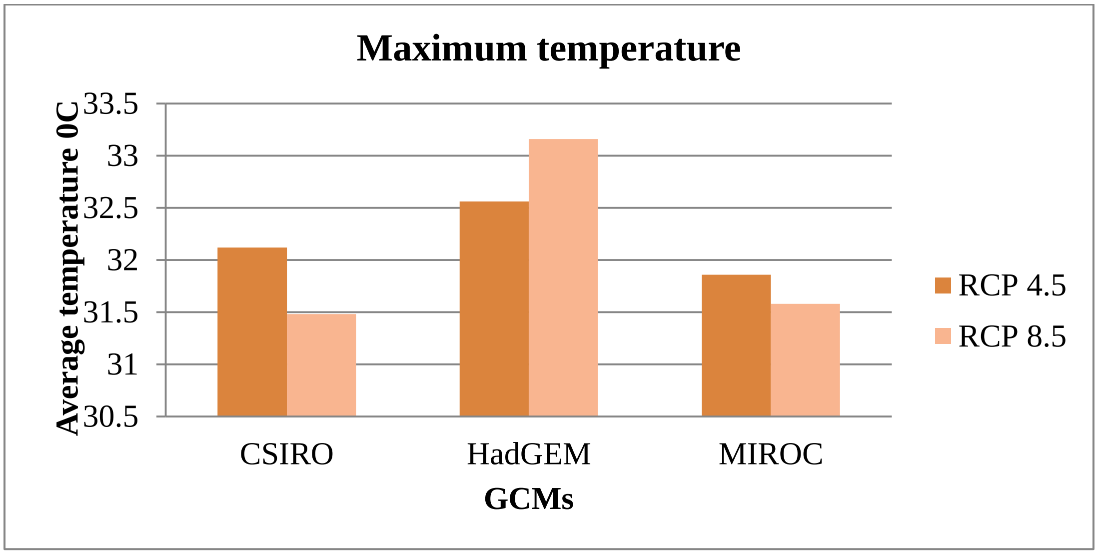
THANK YOU VERY MUCH FOR YOUR PARTICIPATION:

BE BLESSED.

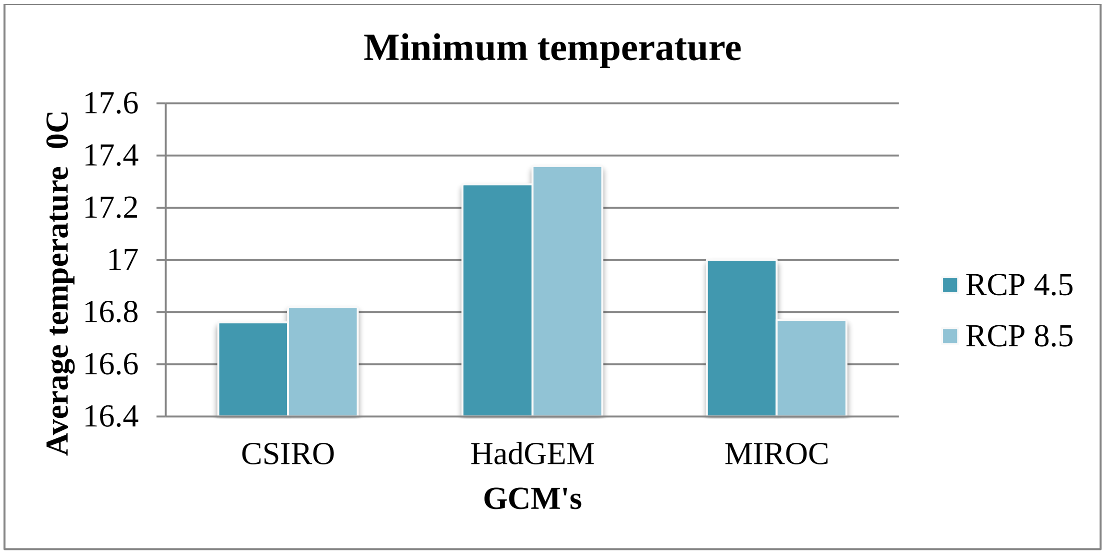
Projected Temperatures



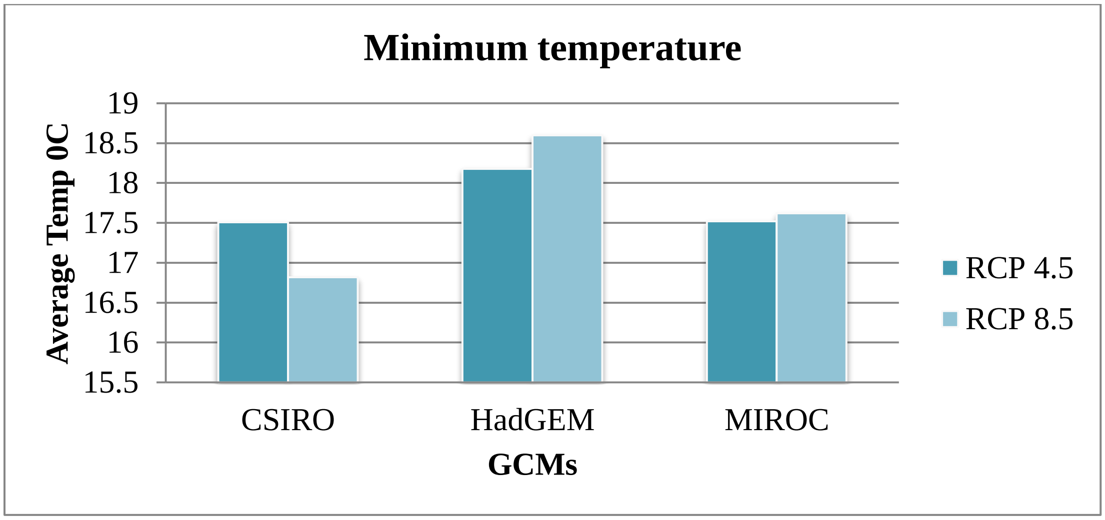
Appendix 2: Projected maximum temperatures for 2030



Appendix 3: Projected maximum temperatures for 2050



Appendix 4: Projected minimum temperatures for 2030



Appendix 5: Projected minimum temperature for 2050