THE IMPACT OF CLIMATE VARIABILITY AND CHANGE ON SWEET POTATO PRODUCTION IN EAST AFRICA

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ABSTRACT

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Over decades, food production in East Africa has been affected by a changing climate, limited use of fertilizers and pest control, inadequate food storage facilities and complex marketing channels that together have led to malnutrition, hunger, and poverty. The six most important food crops feeding the region include cassava, maize, plantains, sweet potatoes, potatoes and paddy rice. Of all these crops, relatively little is known about how climate influences sweet potato growth, development, and yield. Deterministic simulation models for sweet potatoes exist but are relatively young or still in development. Relevant data for climate impact assessments are scarce: detailed agronomic data for sweet potato cultivars grown in East Africa are limited; representative high-quality climate data for the region are scarce, and soils data is only available at coarse spatial resolution. The major objective of this research was therefore to assess the impact of climate variability and change on sweet potato production in East Africa. This was achieved by: (i) developing a modeling framework for use in a deterministic sweet potato crop model, SPOTCOMS, for East Africa; (ii) analyzing trends of historical climate and sweet potato root yields for the period 1980-2009; (iii) developing local climate change scenarios for East Africa for the current time slice 2010s, near future 2030s, mid-future 2050s and distant future 2050s using two representative concentration pathways 4.5 and 8.5 for four Global Climate Models, CSIRO, MIROC5, MRICGC3-M and NorESM-1; and (iv) estimating the impact of projected future climate change on sweet potato production using SPOTCOMS model. Crop coefficients where determined from field trials for four sweet potato cultivars, NASPOT 1, NASPOT 10 0, NASPOT 11 and

SPK004. Results from the calibration and evaluation of SPOTCOMS model gave an index of agreement (IA) of 0.94 and 0.7, a modeling efficiency of 0.9 and 0.31, and a mean bias error of 1.16 t/ha and 0.5 t/ha respectively. Trend analysis indicated that East Africa had warmed on average by 1.5^0C, the rainfall for the February-June season had declined by more than 60 mm while rainfall for the August – December season had increased for most parts of East Africa by more than 50 mm over the past 30 years. The results of future climate projections from Global Climate Models showed mixed results for precipitation and more distinct results for temperatures. Temperatures in the region were projected to rise by 0.8^0C, 1.2^0C and more than 3^0C in the 2030s, 2050s, 2070s respectively and precipitation is projected to consist of more increases in the short rainfall intensity than the long rains for all the three future time slices. The sensitivity analysis showed that SPOTCOMS was sensitive to increase in precipitation and temperature for all the four sweet potato cultivars, NASPOT 1, NASPOT 10 0, NASPOT 11 and SPK004. The projected increase in sweet potato yield in the region coincides with areas that will experience increases in precipitation and temperature. Models with the larger radiative forcing of RCP8.5 showed an overall higher increase in precipitation, temperatures and therefore higher increases in sweet potato yield. All the four cultivars (NASPOT 1, NASPOT 10 0, SPK004 and NASPOT 11) showed similar spatial distribution of yields but SPK004 had lower yields for both historical and projected future periods. Results from this study are useful to all stakeholders interested in sweet potato production in East Africa and the rest of the tropics.

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CHAPTER 1

AGROCLIMATOLOGICAL ASPECTS OF SWEET POTATO PRODUCTION IN EAST AFRICA

1.1 Introduction

Agricultural productivity is strongly dependent on climate variability and change. A recent report by the Intergovernmental Panel on Climate Change (IPCC) concluded that global mean temperatures will increase between 1.1^0C and 4.8^0C from present values by the end of the 21^{st} century (IPCC, 2013). Rainfall may become more variable and erratic with a possible increase in the number and severity of extreme events, especially in tropical areas. The warming is largely associated with increases in atmospheric greenhouse gas concentrations, largely carbon dioxide (CO_2), and, methane (CH_4) and nitrous oxide (N_2O). Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly since 1750 as a result of human activities and now far exceed pre-industrial values. CO_2 increased from a pre-industrial value of 280 ppm to 379 ppm in 2005 (IPCC, 2007b).

There is a high spatial heterogeneity across different regions of the world in terms of projected climate trends and resulting impacts. For example, (IPCC, 2013) noted that the tropical Indian Ocean is likely to feature a zonal pattern with reduced warming and decreased rainfall in regions east of the ocean and enhanced warming and increased rainfall in regions west of the ocean including East Africa. The Indian Ocean dipole of the interannual variability is very likely to remain active, leading to climate extremes in East Africa, Indonesia and Australia (IPCC, 2013).

The El Niño-Southern Oscillation (ENSO) is very likely to remain a dominant mode of interannual variability in the future and the regional rainfall variability it induces may increase (IPCC, 2013). The level of confidence in ENSO projection is very low in East Africa (IPCC, 2013), however, average temperatures are projected to increase by more than 1^0C and with more erratic and variable rainfall possible by 2025 (FEWSNET, 2010, 2012; Hepworth & Goulden, 2008).

Changing climate is likely to lead to unprecedented impacts on agriculture. For example, crop productivity in lower latitudes, especially the seasonally dry and tropical regions, is projected to decrease for even small local temperature increases of 1-2°C, which would increase the risk of hunger (IPCC, 2007a). The frequency of droughts and floods is projected to increase, which would also lead to negative effects on crop production. Relatively more adverse impacts are projected in the lesser developed countries because they tend to be located in already warm tropical areas, rely on climate-sensitive sectors like agriculture, have relatively low incomes, and weak adaptive capacity (Heltberg, Siegel, & Jorgensen, 2009; Mendelsohn, Dinar, & Williams, 2006). Africa has been identified as a region of high crop production risk and projected yield losses due to climate change (Parry, Rosenzweig, & Livermore, 2005; Rosenzweig & Parry, 1994; Schlenker & Lobell, 2010). Crop yields for some countries could decrease by up to 50% by 2020 as a result of declining available agricultural land and shorter growing season length (IPCC, 2007a).

Over decades, food production in East Africa has been affected by a changing climate, limited use of fertilizers and pest control, inadequate food storage facilities and complex marketing channels that together have led to chronic malnutrition, hunger, and poverty (Figure 1.1). We are also uncertain about how future changes in climate will affect crop production. In order to address these challenges, there is a need to invest in research, to encourage the practice of conservation agriculture, and to use climate-smart technologies like growing high yielding, drought tolerant, and nutritious crops.

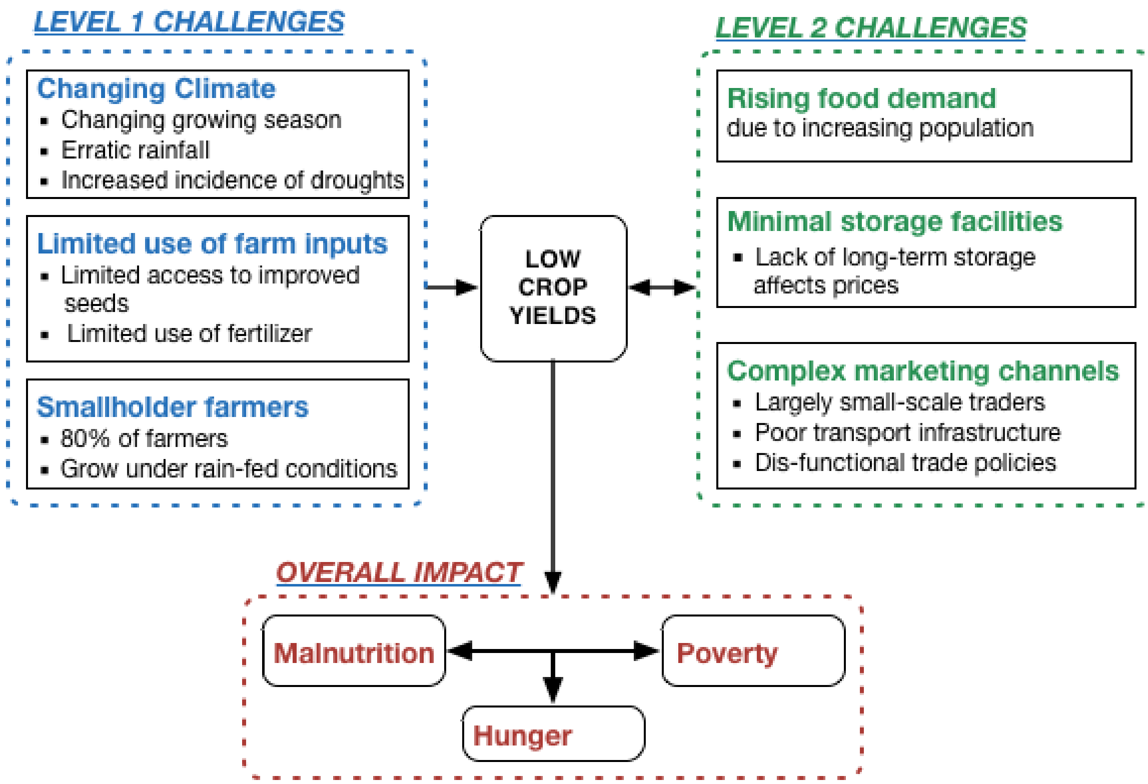


Figure 1. 1 Factors affecting crop production and associated consequences in East Africa
Source: Generated by this research

East Africa is struggling with a food crisis for various reasons. More than 70% of crops grown in East Africa are rain-fed with little or no application of fertilizers. Supplemental irrigation and application of fertilizers would increase crop yields but the majority of farmers are smallholders who cannot afford the cost of the irrigation infrastructure and farm inputs. Farmers rely on the rainy seasons to grow crops in order to feed their families and earn income by selling surplus crops to markets in urban centers.

The proposed research will assess the impact of climate change and variability on sweet potatoes in East Africa. The climate in this region is highly variable characterized by a seasonal movement of the Intertropical Convergence Zone (ITCZ) (Ogallo, 1989), proximity to the Indian Ocean (Goddard & Graham, 1999), and variable topography and presence of Lake Victoria (Anyah, Semazzi, & Xie, 2006). The climate, therefore, supports growing of a wide range of food and cash crops in the region.

1.2 Climate change and variability, and physical characteristics of East Africa

The topography of East Africa varies from 0 m on the coast of the Indian Ocean to 5, 890 m at the highest peak of Mt. Kilimanjaro. The regional climate is controlled by the presence of the Intertropical Convergence Zone; Indian Ocean; Variable topography (Ogallo, 1989; Goddard and Graham, 1999; Anyah et al., 2006). The region receives a bimodal annual rainfall ranging between 500 mm to over 2,500 mm (FEWSNet, 2010, 2012) and mean annual temperatures range between 8.1^{0}C (at high elevations) to 32^{0}C (FEWSNet, 2010, 2012). Figure 1.2 below shows the major physical features and the countries that constitute East Africa.

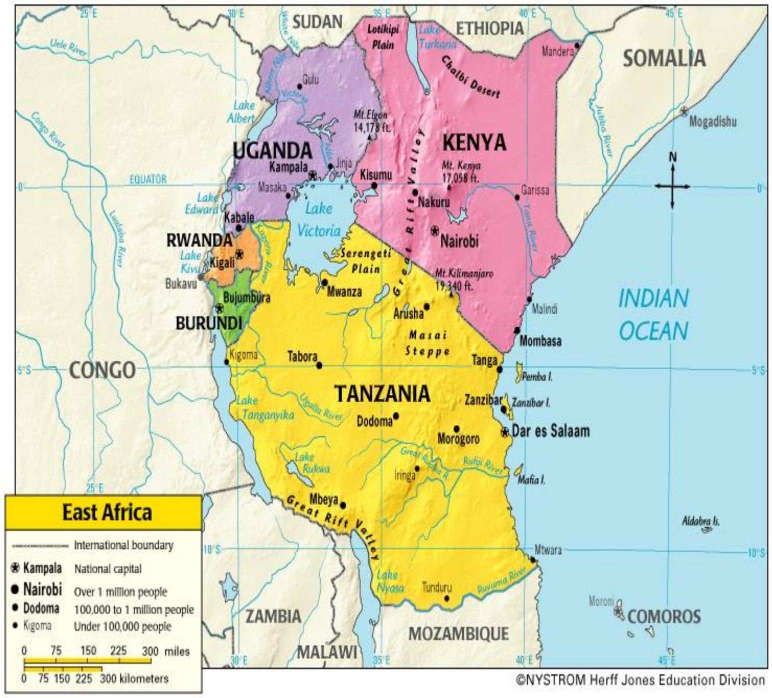


Figure 1. 2 Map of East Africa

The length of the long rains season, known to originally fall in the months March to May, has decreased while that of the short rains, originally known to be in the months of September to December, has increased over the past 30 years (FEWSNet, 2010; 2012). East Africa has experienced increased in the incidence of droughts and floods (Uganda Meteorological Department, 2010) and temperatures have increased by 0.8^{0}C over the past 30 years (FEWSNet, 2010, 2012). As a result of these reported changes and variability in climate, crop failures have been reported in the region (e.g., Jassogne et al., 2013) which implies that agricultural production systems in East Africa are very sensitive to climate.

Global warming arising from an increase in greenhouse gases (GHGs) is likely to impact the regional climate of East Africa (IPCC, 2013). Temperatures are projected to increase by an average of 1.5^{0}C from their current numbers, and rainfall will become more erratic and variable in the next 20 years (IPCC, 2013). The long rains growing season will shorten in most areas while short rains will lengthen (IPCC 2007; McSweeney et al., 2008; Hepworth and Goulden, 2008; FEWSNET, 2010, 2012; Cook and Vicky 2013). Increases in GHGs will directly impact crop species especially C_3 crops through CO_2 enrichment (Bhattacharya et al 1985; 1990; Siqinbatu et al., 2013). Droughts, floods, shortening of growing seasons, increasing temperatures will lead to high crop production risks and large yield losses in East Africa (Rosenzweig and Parry, 1994; Parry et al., 2005; Thornton et al., 2009; Schlenker and Lobell, 2010; Moore et al., 2012; Arndt et al., 2012).

1.3 Regional agriculture

East Africa grows a number of crops including ones used mainly for income generation such as coffee, cotton, tea, sugarcane and various food crops. The six most important food crops feeding the region include cassava, maize, plantains, sweet potatoes, potatoes and paddy rice (FAO, 2013). Figure 1.3 shows that crop production for all the six major food crops has been increasing over the past 3 decades with cassava and maize yields being always above other food crops in the region.

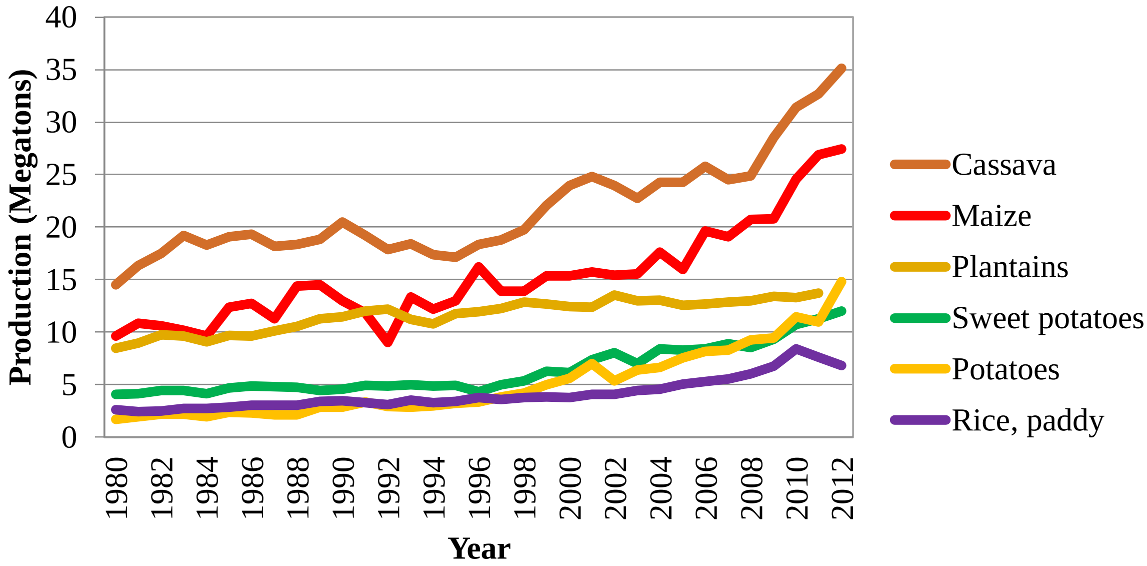


Figure 1. 3 Top 8 crops in East Africa

On a country level, sweet potatoes are among the top four food crops grown in each of the three East African countries used in this research as shown in Figure 1.4. In Uganda, the top four most important food crops from highest to low importance are plantains, cassava, sweet potatoes and maize; in Kenya, they are maize, potatoes, sweet potatoes, and cassava; and in Tanzania, they are cassava, maize, sweet potatoes and paddy rice. Out of the three countries, Uganda has the highest annual sweet potato production of more than 2,000 tonnes (Figure 4a) while Kenya has the least production of about 500 tonnes (Figure 4b). In terms of annual trends, Tanzania showed the highest rise in production from the year 2000 to 2010 with the present production levels even reaching and surpassing those of Uganda (Figure 4d).

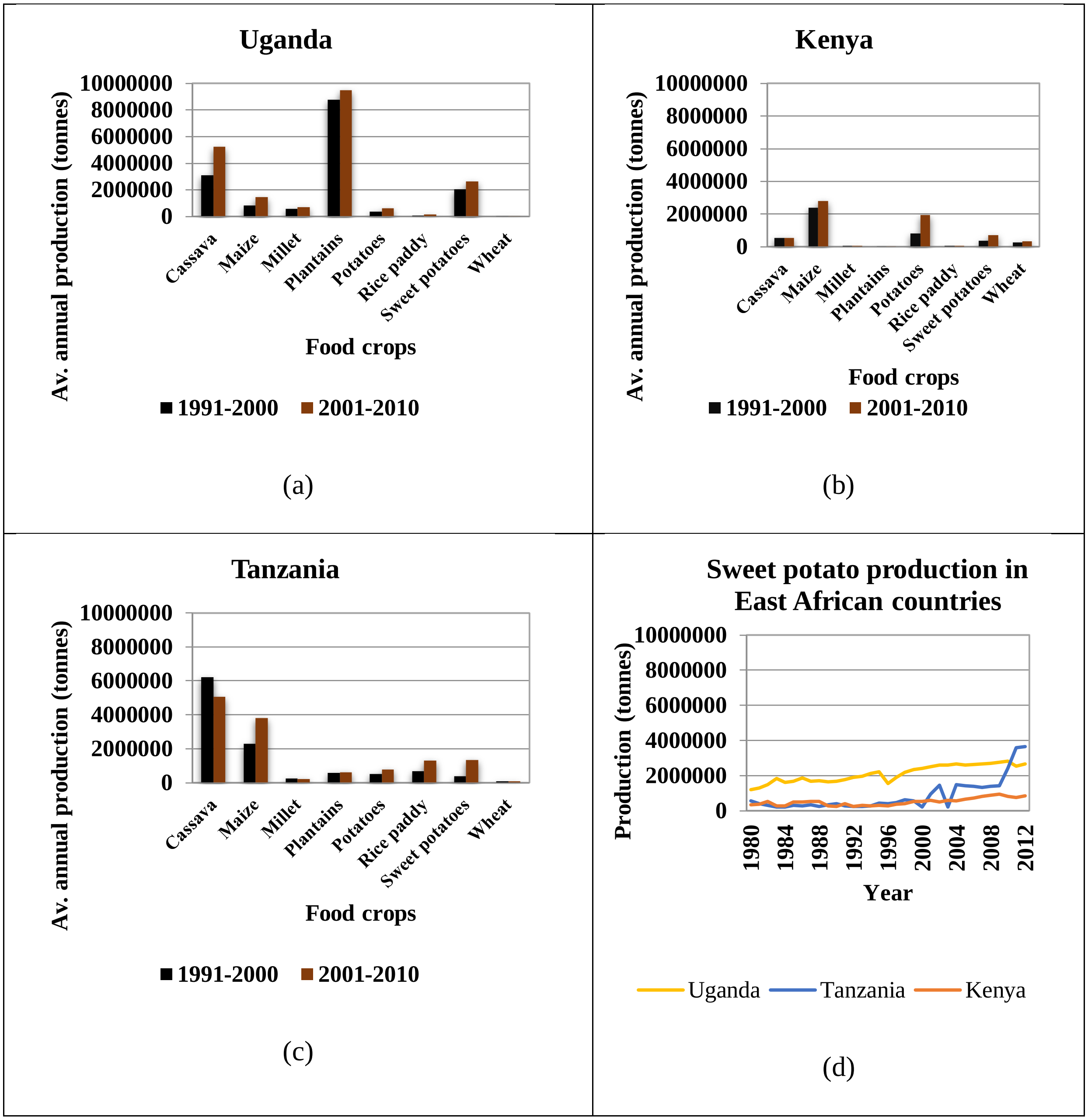


Figure 1. 4 Average annual production for the top eight staple crops in East Africa, Source: FAO, 2013

Besides being one of the four most important stapes in the region sweet potatoes plays several significant roles in the agricultural systems in East Africa. It is a crop grown by resource-poor farmers, it is very nutritious, richer in vitamin A than cassava, maize and plantain (Mwanga et al., 2003), it can sustain families up to six months through piecemeal harvesting, it can be used as both food and animal feed (Bashaasha, Mwanga, p'Obwoya, & Ewell, 1995), it requires relatively little soil nutrients (Slathers et al., 2005) and it is a drought and heat tolerant crop (Gomes & Carr, 2003).

1.4 Climate requirements for sweet potatoes

(Togari, 1950) and (Villordon, LaBonte, Solis, & Firon, 2012) emphasized that the early-season (first 20 days) growing environment has a direct and significant impact on storage root initiation and thus final yield. Temperature stress is one of the most crucial limitations on crop growth and development (Wrigley, 1994) and causes irreversible damages to the plant processes and thus affecting final yield.

Temperature and CO_2 levels can significantly affect sweet potato growth (Loretan et al., 1994). Higher storage root weights and numbers are favored by growing sweet potatoes in varied temperatures and thermoperiods such as growth in a sand culture at 29^0C (16-h light period) and 20^0C (dark) compared to those grown at a constant temperature of 29°C (same photoperiod, (Kim, 1961; Loretan et al., 1994). In a study by (Spence & Humphries, 1972), working with rooted single leaves of sweet potatoes, obtained optimum storage root formation and development was obtained when the soil temperature was 25^0C, whereas soil temperatures of 15 and ^{350C} were inhibitory to storage root formation. Growth was reduced 50% with a temperature reduction of from 21.1 to 15.6°C (Jarret & Gawel, 1991). Reduction of photoperiod from 16 to 4 h produced smaller, slightly chlorotic, but otherwise normal plants (Jarret & Gawel, 1991).

(Gajanayake, Reddy, Shankle, Arancibia, & Villordon, 2014) is the first study that quantified the functional relationships of root initiation, growth, development, and biomass partitioning of sweet potato in response to a wide range of temperatures, where the crop is grown today and expected to grow in future under projected changes in climate. They found that maximum total root numbers produced increased with temperature from 20/12 to 30/22°C, but differed only between the two extreme temperature treatments (20/12^{0}C and 40/32°C). When the temperature increased from 17.4 to 36.4°C, time to 50% total root initiation was reduced by 4.5 days. Having a well-developed root system during the early growth stages of the crop was extremely crucial for both development of the shoot system as well as for the process of storage root development of sweet potato. But this is study looked at the first 59 days after planting.

Elevated CO_2 concentrations were also reported to increase sweet potato storage root yields possibly as a result of a shift in the distribution of photosynthate from the leaves to the storage roots (J. R. Allen, Bhattacharya, Lu, Pace, & Rogers, 1985; Bhattacharya, Biswas, Battacharya, Sionit, & Strain, 1985).

The cessation of root elongation, primary and secondary cambia growth, an increase of radial growth or bulking by an increased rate of cell division, cell proliferation, and cell expansion is associated with the deposition of starch (Ravi, Nascar, Makeshkumar, & Binoy Babu, 2009). Among environmental factors, high air temperature causes reduction in storage root formation and growth through the changes in phytohormones synthesis and activation (Ravi & P., 1999) and dry matter partitioning and bulking of storage roots in sweet potato and tubers in potato (Solanum tuborosum L.) (Van Dam, Kooman, & C., 1996).

Greater yields depend on an early development of source (leaf area) for optimum light interception and sink (both initiation and enlargement of storage roots) in sweet potato. Apart from the sink organs, enhancement of source organ functions and capacity are crucial to increasing sweet potato yield. To achieve high dry matter production through photosynthesis process, it is important to develop an optimum leaf area. Also, the photosynthesis in sweet potato is sensitive to elevated temperature (>35°C). According to Indira and Kaberathumma (1988), three important physiological events in the growth phase of sweet potato are responsible for final crop productivity, namely storage root initiation, storage root development, and storage root maturity. Both air and soil temperature regulate the competition between shoot and storage root growth in sweet potato (Gajanayake et al., 2014; Ravi et al., 2009).

1.5 Characteristics and adaptive potential of sweet potato cultivars in Uganda

1.5.1 Introduction

Due to the high adaptive potential of sweet potatoes, Africa is among the top producers with the highest production coming from Uganda in East Africa (Bashaasha et al., 1995). Even with high production and high nutritious values of sweet potatoes in Uganda, malnutrition problems still do exist in the country. For example, 20% of children and 19% of women have vitamin A deficiencies (Opinion Research Corporation Macro International Inc (ORC Macro), 2006). Vitamin A deficiency (VAD) has negative effects such as increased exposure of children to common illness, stunted growth, development, vision and reduced immune systems (Tumwegamire et al., 2007) and VAD claims between 15,000 to 60,000 lives annually (Ruel, 2001). These statistics paint a picture that something is probably wrong. One possibility could be that the crops produced and consumed, especially sweet potato varieties may not be rich enough in vitamins, or that vitamin-rich crops are produced and consumed during a particular season leaving families to live without any source of vitamins for the rest of the time. There is, therefore, a need for all stakeholders to devise means to address this problem, one way of which is to have a collection of the crop characteristics and then identify ways to help families have a quality diet across the year.

The aim of this paper is to integrate and identify the most productive sweet potato cultivars from existing literature using characteristics including maturity period, yield, root quality, resistance to pests and diseases, root flesh color, and abundance. Having a collection of information about the sweet potato varieties that have been researched on is valuable to researchers interested in crop breeding, modeling and pathology studies. The paper begins by providing an overview of the sweet potato farming systems in Uganda and a detailed analysis of the sweet potato cultivars based on published work and the organizations that help in the dissemination of planting materials and any other relevant information to the farmers. The paper presents the major constraints experienced by farmers and finally, highlights the role of participatory and adaptive research in developing suitable crop varieties and general sweet potato production systems in Africa.

1.5.2 Sweet potato farming systems in Uganda

Farming systems of sweet potato in Uganda vary from mono-cropping to mixed cropping systems. Sweet potato is either mono-cropped or inter or relay cropped with other crops such as legumes e.g., beans, or cereals like maize, millet, and sorghum (Ewell and Mutuura 1994: Bashaasha et al 1995). This enables households especially in rural areas to have a constant food supply and various food options during the year. Sweet potato is normally grown in crop rotations which are decided upon differently by farmers in the region in Uganda and more importantly, according to the resources and priorities of a given household (Bashaasha et al., 1995). The crop rotations of sweet potato potatoes for the different ecological zones in Uganda are provided in Table 1.1. It is mainly grown by women in small householder farming systems for food and income generation (Bashaasa et al., 1995; (R. W. Gibson, Mwanga, Namanda, Jeremiah, & Barker, 2009).

Table 1. 1 Crop rotations of sweet potatoes in Uganda. Source: Bashaasha et al., 1995.

Region	**Crop rotation**
High latitude zones (e.g., Kabale)	fallow > sorghum > sweet potato > beans/maize fallow > peas > sweet potato > sorghum > irish potato
(e.g., Mbale)	cotton > millet > sweet potato/cassava
Pastoral dry to semi-arid rangeland zone	fallow > maize/beans > cassava/millet > sweet potato > beans/maize or millet > cotton > cassava > fallow
Northern and eastern short-grassland zone	fallow > cotton > millet > sesame > cassava/fallow or fallow > sesame > cassava > sweet potato > maize/fallow
Southern and western tall-grassland zone	Fallow > sweet potato > maize/bean >millet > cassava > sweet potato or Fallow > maize/beans > sweet potato > cassava > millet

The main source of planting materials for growing sweet potatoes by households is by use of domestic wastewater to grow vines and planting sweet potato roots in a nursery, watering them for4-6 and then transplanted to actual plots. Sweet potato is planted on ridges, mounds of about 0.5m high and occupying an area of about 1 square meters (Gibson et al., 2008) or on flat ground. It is planted following the bimodal part of the rainfall between March-May and October – December (Ewell and Mutuura 1994; Bashaasha et al 1995). Planting materials are mainly vines and sometimes sizeable roots accumulated by households using irrigation and domestic wastewater (Gibson et al 2009). In drier areas, planting materials are conserved by planting vines in areas with available water such as wetlands, areas near water holes, and sometimes by physical watering in the backyard (Gibson et al., 2009).

Various sweet potato varieties with varying maturation times are grown on the same plot during the same season and sometimes at different times in order to allow for a long time of harvest. Most subsistence households practice in-ground storage and piecemeal harvest whereby only enough roots are harvested (Ebregt, Struik, Odongo, & Abidin, 2007; Hall, Bocket, & Nahdy, 1998; Smit, 1997). This form of staggering planting and planting of different varieties enable the households to go through dry periods by having mature roots stored in the ground for up to six months and piecemeal harvesting. However, the sweet potato production still undergoes a number of challenges and constraints that have led to low yields in Uganda.

1.5.3 Sweet potato varieties in Uganda

The choice and preference of sweet potato varieties by farmers differ from individual to individual. Farmers use characteristics such as yield, time to reach maturity, root color, root size, root shape, root quality, sweetness, pest and disease resistance, and marketability (Bashaasha et al. 1995). There has been a considerable amount of research on the characteristics of sweet potato varieties grown in Uganda. Some studies provide detailed information about the characteristics of varieties while others provide much less information. The varieties are either local landraces existing within communities or officially released landraces got from other communities and distributed across the country, and others are bred and tested at the National Crops Resources Research Institute (NaCRRI) in Namulonge and later released to communities. In this paper, we reviewed the literature and collect characteristics on all the recorded varieties and we made comparisons of the varieties. The synthesized information from this review is useful for researchers and other stakeholders interested in understanding sweet potato production in Uganda. This work focused on varieties that had been published in articles but was noted that there were many more varieties existing in Uganda whose characteristics have not yet been documented.

The varieties were presented under two categories; non-orange fleshed sweet potato varieties (Table 1.2) and orange-fleshed sweet potato (OFSP) varieties (Table 1.3). Of the non-OFSP, the released varieties include: Tanzania, Bwanjule, New Kawogo, Tororo 3, Wagabolige, and Sowola (Mwanga et al., 2001); NASPOT 1, NASPOT 2, NASPOT 3, NASPOT 4, and

NASPOT 6 (Mwanga et al., 2003); NASPOT 11 (Gibson et al. 2011); and, Vita A and Kabode (Namanda et al., 2011). It is not very clear from the literature whether the last two varieties are non-OFSP or OFSP. The released OFSP include NASPOT 5 (Mwanga et al., 2003); Ejumula and Kakamega or SPK 004 (Mwanga et al., 2005); and NASPOT 7, NASPOT 8, NASPOT 9 O', and NASPOT 10 O' (Mwanga et al., 2009).

Table 1. 2 Non –Orange varieties.

Cultivar	**Root Flesh Color**	**References**
Dimbuka	Cream	Mwanga et al. 2005; Yanggen and Nagujja 2006; Mwanga et al 2007a; Gibson et al. 2011; Tumwegamire et al. 2011b
Dimbuka-Bukulula	Cream	Mwanga et al. 2009
Kyebandula	Cream	Bashaasha et al. 1995; Gibson et al. 1997; Hall et al. 1998; Mwanga et al. 2003a; Tumwegamire et al. 2011a
Old Kawogo	Cream	Bashaasha et al. 1995; Gibson et al. 1997; Mwanga et al. 2003a;
Magabi		Bashaasha et al. 1995;
Sukali		Bashaasha et al. 1995;
Bitambi	Cream	Bashaasha et al. 1995; Gibson et al. 1997; Mwanga et al. 2003a; Tumwegamire et al. 20011a; Tumwegamire et al. 2011b
Tanzania-RLr	Light Orange/ Pale Yellow	Bashaasha et al. 1995; Gibson et al., 1997; Mwanga et al. 2001; Mwanga et al. 2003a: Mwanga et al. 2005; Yanggen and Nagujja 2006; Gibson et al. 2009; Mwanga et al. 2009; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Mukazi	Cream	Hall et al. 1998; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Araka	Cream	Mwanga et al. 2005; Namanda et al. 2011; Tumwegamire et al. 2011a
Bwanjule-RLr	White	Mwanga et al. 2001; Mwanga et al. 2003a; Mwanga et al. 2009; Tumwegamire et al. 2011a

Table 1.2 (Cont'd)

Cultivar	Root Flesh Color	References
New Kawogo-RLr	White/Cream	Gibson et al. 1997; Mwanga et al. 2001; Mwanga et al. 2003a; Mwanga et al. 2005; Yanggen and Nagujja 2006; Gibson et al. 2009; Mwanga et al. 2009; Gibson et al. 2011; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Tororo-3-RLr	Cream	Mwanga et al. 2001; Mwanga et al. 2003a; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Wagabolige-RLr	White/Cream	Mwanga et al. 2001; Mwanga et al. 2003a; Tumwegamire et al. 2011a
Sowola -RV	Cream	Mwanga et al. 2001; Mwanga et al. 2003a; Mwanga et al 2005; Mwanga et al. 2007a; Mwanga et al. 2009; Tumwegamire et al. 2011b
Bunduguza	Light Yellow	Mwanga et al 2005; Yanggen and Nagujja 2006; Mwanga et al. 2009; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
NASPOT 1 - RV	Pale Yellow	Mwanga et al. 2003a; Gibson et al. 2008; Mwanga et al. 2009; Gibson et al. 2011
NASPOT 2- RV	Cream	Mwanga et al. 2003a; Gibson et al. 2008; Mwanga et al. 2009
NASPOT 3- RV	Cream	Mwanga et al. 2003a; Gibson et al. 2008; Mwanga et al. 2009
NASPOT 4- RV	Pale Yellow	Mwanga et al. 2003a; Gibson et al. 2008; Mwanga et al. 2009
NASPOT 6- RV	White	Mwanga et al. 2003a;
NASPOT 11-RV		Gibson et al., 2011
Vita A - RV		Namanda et al. 2011
Kabode - RV		Namanda et al. 2011
Araka - lr	White	Mwanga et al 2005; Mwanga et al. 2009; Namananda et al. 2011; Tumwegamire et al. 2011b
Osukut - lr		Namanda et al. 2011
Silk		
Rwanubende		Hall et al. 1998
Yosefu		Hall et al. 1998
Muguma		Hall et al. 1998
Kahungezi		Hall et al. 1998
Kalebe	Cream	Hall et al. 1998; Yanggen and Nagujja 2006; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b

Table 1.2 (Cont'd)

Cultivar	Root Flesh Color	References
Osapat	Yellow	Mwanga et al. 2005; Yanggen and Nagujja 2006; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b; Yada et al. 2011
Kassim		Mwanga et al. 2005
Kampala		Mwanga et al. 2005; Gibson et al. 2008; Tumwegamire et al. 2011b
Kenya		Mwanga et al. 2005; Yanggen and Nagujja 2006;
Koromojo		Mwanga et al. 2005
Otada		Mwanga et al. 2005; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Liralira		Mwanga et al. 2005

Table 1. 3 Orange-fleshed varieties

Cultivar	Root Flesh Color	References
NASPOT 5- RV	Orange	Mwanga et al. 2003a; Mwanga et al. 2005; Mwanga et al. 2009
NASPOT 7- RV	Intermediate Orange	Mwanga et al. 2009
NASPOT 8- RV	Pale Orange	Mwanga et al. 2009
NASPOT 9 O-RV	Intermediate Orange	Mwanga et al. 2009
NASPOT 10 O-RV	Dark Orange	Mwanga et al. 2009
Ejumula-RLr	Orange	Mwanga et al. 2005; Yanggen and Nagujja 2006; Mwanga et al. 2007a; Mwanga et al. 2007b; Namanda et al. 2011; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Kakamega (SPK 004)	Orange	Mwanga et al 2005; Yanggen and Nagujja 2006; Mwanga et al. 2007a; Mwanga et al. 2007b; Namanda et al. 2011; Tumwegamire et al. 2011a
Abuket 1	Orange	Gichuki et al. 2005; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Abuket 2	Light Orange	Gichuki et al. 2005; Tumwegamire et al. 2011a; Tumwegamire et al. 2011b
Kala	Orange	Mwanga et al 2005; Yanggen and Nagujja 2006; Mwanga et al. 2007a; Mwanga et al. 2009; Tumwegamire et al. 2011a; Yada et al. 2011
Edule	Orange	Yanggen and Nagujja 2006;
Gweri	Orange	Gichuki et al. 2005

1.5.3.1 Maturity

An analysis of information in Table 3 from the literature shows that Sowola takes 100-120 days to reach maturity while others like Tanzania, Dimbuka-Bukulula, Bwanjule, Dimbuka, Tororo-3, Wagabolige, NASPOT 1, NASPOT 2 and NASPOT 6 take between 120-130 days to mature. Mukazi and Kyebandula were also ranked among the early maturing varieties in a study carried out by Hall et al. (1998) but no specific maturity date was provided. For the OFSP in Table 1.4, on the other hand, NASPOT 10 O and NASPOT 7 take 110 days and 115 days respectively to reach maturity while NASPOT 8, Ejumula, Kakamega, NASPOT 5 and NASPOT 9 take between 120-150 days.

1.5.3.2 Yield

In terms of yield, non-OFSP varieties in Table 3 gave the highest yield with an average yield of 29t/ha for NASPOT 1, Sowola (25.6 t/ha), Dimbuka-Bukulula and NASPOT 3 (25t/ha), NASPOT 6, Wagabolige and Araka (23.9). A most recently released variety NASPOT 11 was also reported to have yielded as much as NASPOT 1(Gibson et al., 2011). The rest of the non-OFSP varieties had below 21t/ha. The OFSP varieties with the highest yield were NASPOT 5 with 23t/ha and NASPOT 7 with 20.4t/ha.

The root dry matter content for most sweet potato varieties is over 30% but Mukazi has the highest value of 35.8%, followed by NASPOT 3 with 35%, Sowola, and NASPOT 6 with 34% (Table 3). For the OFSP varieties, the highest root dry matter content is given by Kakamega with 33.3%. This is a very important ratio for breeders to understand the proportion of biomass partitioning for a sweet potato plant. A high ratio shows that a good proportion of nutrients are used by the plant in developing roots.

Table 1. 4 Characteristics of selected non-orange fleshed varieties

Cultivar	Maturity	Av. Yield (kg/ha)	Root Quality			Abundance	Resistance to pests & diseases		
			Root dry matter content (%)	Taste sweetness	β-Carotene (µg/100g)		Weevils	SPVD	Alternaria Stem Blight
Mukazi	Early	8.1	35.8	not recorded		High			
Sowola	100-120	25.6	34	moderate			HS	MR	
Tanzania	120	22.9	32	moderate		High	S	MR	MR
Dimbuka-Bukulula	128	25	32.4	moderate	13.3-24.1		S	S	MR
Kyebandula	Early	high	high	not recorded		High			
Bwanjule	120-150	21.4	30	moderate			MR	R	
Dimbuka	120-150	19.7	31.5	moderate	24-32		S	S	MR
Tororo-3	120-130	18	31	moderate			MR	MR	
Wagabolige	120-150	24.1	33	moderate				R	
NASPOT 1	120-150	29	33	sweet		High	S	MR	
NASPOT 2	120-150	21	29	sweet			S	R	
NASPOT 6	120-150	24	34	moderate			MR	MR	
New Kawogo	130-150	23.3	33	moderate		High	MR	HR	HS
NASPOT 3	130-150	25	35	sweet			MR	R	
NASPOT 4	130-150	21	33	sweet			MR	R	
Araka		23.9	29					R	
NASPOT 11		~28					S	MR	
Bunduguza		~23	31.5			High			

HS – High Susceptibility, S – Susceptibility, MR – Moderately Resistant, R – Resistant, HR – High Resistance

1.5.3.3 Taste

Taste is a very important factor used by consumers of sweet potatoes in Uganda. A variety with a sweet taste is more preferred to one with less sweet taste. For the non-OFSP, the released varieties NASPOT 1, NASPOT 2, NASPOT 3 and NASPOT 4 have sweet tastes and therefore may be consumed more than the local landraces (see Table 1.4). NASPOT 5 in Table 4 has a sweeter taste than the rest of the OFSP varieties.

1.5.3.4 Abundance

Abundance is also an important factor used by farmers to determine the varieties they plan on planting in a given season. The more abundant varieties vary for different regions in the country. However, the most common varieties across the country include Mukazi, NASPOT 1, Kyebandula, New Kawogo, Bitambi, Tanzania and Bunduguza (Bashaasha et al 1995; Hall et al., 1998; Mwanga et al. 2001; Mwanga et al 2003a; Bua et al., 2005). The most common local varieties per region from highest to low abundance include: Central – Dimbuka, Kalebe, New Kawogo, Silk, Munyera, Kyebandula; Eastern – Bunduguz a, Araka, Kigayire, Silk, Tanzania; Northern – Liralira, Koromojo, Nyakenya, Ombivu, Nyaromayo; Western – Kyebandula, Kahogo, Mugumira, Kyokyokyemba (Bua et al 2005). Tanzania is a regional variety as it is widely grown in East African countries and locally known by different names. For example, it is called SPN/O in Tanzania, Enaironi in Kenya, Chingovwa in Zambia and Kenya in Malawi (Mwanga et al 2001).

1.5.3.5 Resistance to pests and diseases

The literature considers mainly three categories; weevils, sweet potato virus disease (SPVD) and Alternaria stem blight (see Tables 1.3 and 1.4). Bwanjule, Tororo-3, NASPOT 6, New Kawogo, NASPOT 3 and NASPOT 4 and NASPOT 5 are moderately resistant to sweet potato weevils. Most orange-fleshed such as sweet potato (OFSP) varieties, and Sowola, Tanzania, Tororo-3, NASPOT 1 and NASPOT 6 are moderately resistant to SPVD. New Kawogo was reported to have a high resistance and Bwanjule, Wagabolige and NASPOT 2 are also resistant to SPVD. All OFSP varieties, some non-OFSP varieties such as Tanzania, Dimbuka-Bukulula, and Dimbuka are moderately resistant to alternaria stem blight. Therefore, successful production of a variety in an area should put into consideration the nature and type of pests and diseases present in the area.

Based on all the defined characteristics in the preceding sections, four cultivars were selected for the later part of this study (Table 1.5). That is, for crop- model development and for assessment of the impact of climate change on sweet potato production in East Africa.

Table 1. 5 Characteristics of selected orange-fleshed varieties (abundance not known)

Cultivar	Maturity (days)	Av. Yield (t/ha)	Root Quality			Resistance to pests & diseases		
			Dry matter content (%)	Taste sweetness	β-Carotene (µg/100g)	Weevils	SPVD	Alternaria Stem Blight
NASPOT 10 O	110	16		Moderate	185.6-342.8	S	MR	MR
NASPOT 7	115	20.4		Moderate	44.3-192.7	S	MR	MR
NASPOT 8	120	17.8	32	Moderate	85.6-219.3	S	MR	MR
Ejumula	120-150	18.8	30.1	Moderate	206.3	S	S	MR
Kakamega	120-150	14.9	33.3	Moderate	376-3760	S	MR	MR
NASPOT 5	120-150	23	30	Sweet		MR	MR	
NASPOT 9	125	16.5	30.1	Moderate	206.3-460.3	S	MR	MR

HS – High Susceptibility, S – Susceptibility, MR – Moderately Resistant, R – Resistant, HR – High Resistance

1.5.4 Farmer support and dissemination of planting materials

The importance of this section is to highlight the organizations playing a significant role in the distribution of planting materials for the different varieties and providing general support to sweet potato farmers in Uganda. The organization is distributed across the country, see Table 1.6. The organizations are government, not for profit, or community-based organizations (CBO). The organizations help in the multiplication and dissemination of new and improved sweet potato varieties, promotion of orange-fleshed sweet potato to avert vitamin A deficiency. They also help in sensitization of farmers and all stakeholders about the importance of growing and consuming orange fleshed varieties that are rich in vitamin A. Examples of such institutions include the ministry of Health in collaboration with Volunteer Efforts for Development Concerns (VEDCO) and the National Agricultural Research Organization (NARO) successfully conducted sensitizations in Luwero district in central Uganda in 2001 (VEDCO, 2001) and Save the Child (NGO), Makerere University, Department of Agricultural Extension, and World Vision sensitized stakeholders (Mwanga, Stevenson, & Yencho, 2005).

Table 1. 6 Organizations helping farmers in sweet potato production

Region	Name of organization	Type of Organization (NGO/CBO)	Reference
Central	Buganda Cultural and Development Foundation (BUCADEF)	CBO	Yanggen and Nagujja 2006; Gibson et al. 2008; Gibson et al. 2009
Central	Volunteer Effort for Development Concerns (VEDCO)	CBO	VEDCO 2001
Central	Tusitukire wamu Kabulanaka Farmers' Association (TUKAFA)		Gibson et al. 2011
Central	Rakai District Farmer's Association (RADFA)	CBO	Yanggen and Nagujja 2006
Central	Community Enterprise Development Organization (CEDO)		Yanggen and Nagujja 2006
Central	Adventist Development and Relief Agency (ADRA)	NGO	Yanggen and Nagujja 2006
Central	Concerned Women (COWO)	NGO	Yanggen and Nagujja 2006
Central	Masaka District Development Organization (MADDO)	NGO	Yanggen and Nagujja 2006
	Save the Child	NGO	Mwanga et al. 2005
Country-wide	National Agricultural Research Organization	NGO	Gibson et al. 2008; Gibson et al. 2009
East	Soroti Sweet potato Producers Association (SOSPPA)	CBO	Gibson et al. 2009
East	Soroti Cathoric Diocese Development Organization (SOCADIDO)	NGO	SOCADIDO 2001
Western	Hoima District Farmers Association (HODIFA)	CBO	Yanggen and Nagujja 2006
Western	Sub-county Offices	Government	Yanggen and Nagujja 2006
Western	District Agricultural Office	Government	Yanggen and Nagujja 2006
Western	Africare	NGO	Yanggen and Nagujja 2006
Northern	James Arwata Foundation (JAF)	NGO	Yanggen and Nagujja 2006
Country-wide	Makerere University	Government	Mwanga et al. 2005
Country-wide	World Vision	NGO	Mwanga et al. 2005(Mwanga et al., 2005)

1.5.5 Constraints to sweet potato production in Uganda

Sweet potato production is affected by a number of constraints that compromise its potential in being very productive. The average yield of sweet potato (4t/ha) is much lower than the potential yield of 25t/ha. Various constraints responsible for the low production include; pest and diseases, drought, vine scarcity, lack of capital, high labor requirements, poor yields, low prices, animal destroy the crop, lack of land, poor markets, and crop rotting (Yanggen & Nagujja, 2006).

The major disease constraints affecting sweet potatoes include the sweet potato virus disease (SPVD), weevil, and physiological lack of vigor (R. W. Gibson et al., 2009). Major sweet potato pests include sweet potato weevil (*Cylas punticolis, C.brunneus, and C. formicarius*), butterflies, mole rats, other rodents and wild beasts (Bashaasha et al., 1995; Ewell & Mutuura, 1994; R. W. Gibson et al., 2009). Intercropping sweet potato with corn, soybean and corn + soybean reduces the damage of sweet potato weevil (Yaku, Hill, & Chiasson, 1992) while pesticides and fertilizer application, and rouging of the diseased plants (Bashaasha et al., 1995; R. W. Gibson et al., 2009) are the main ways to regulate virus diseases of the crop. Like in most developing countries, fertilizer application in sweet potato farming systems in Uganda is very low leading to poor yields (Anon, 1993). However, even in instances of low farm inputs, some sweet potato varieties give a higher yield than others.

1.5.6 Participatory and adaptive research on sweet potato production

Participatory breeding and adaptive research have unique contributions to make to the constraints faced by sweet potato smallholder farmers in Uganda and African countries in general. Farmers, community-based and non-profit organizations, and agricultural extension have been instrumental in enhancing production and research in sweet potato agricultural systems in Uganda. Some literature has highlighted the involvement of farmers in participatory plant breeding and participatory variety selection (Richard. W. Gibson, Byamukama, Mpembe, Kayongo, & Mwanga, 2008; Richard. W. Gibson, Mpembe, & Mwanga, 2011) with positive results in terms of the final product from the research and also from the farmers experience and fulfillment in contributing towards the whole research process. There is a wide body of literature on participatory research approach but only a few selected articles are used in this section to briefly orient the reader. Then a few success stories for sweet potatoes and other crops are presented to highlight the importance of this approach in enhancing agricultural production.

In an agricultural context, participatory research can be functional oriented and empowering involving farmers (Okali et al., 1994) and other stakeholders such as extension officers, non-governmental organizations, and scientists. Participatory research improves crops and genetic diversity, the efficiency of the research services in identifying adaptive technologies, and empowers rural communities to influence the agendas of and to benefit from the knowledge in formal research (Sutherland 1998; Morris and Bellon, 2004; Humphries et al., 2005). In designing a model of participatory research for bean improvement, Bulter et al (1994) observed that farmers' participation is critical in research because farmers usually know the problem and needs on their farms, and whether they will use the new variety or not. Therefore, in order to achieve the most of out of participatory research, the research should be collaborative (Sperling et al., 1993; Bentley, 1994; Sutherland 1998; Witcombe et al., 2005a), contractual, consultative and collegiate (Sutherland, 1998), decentralized (Ashby & Sperling, 1994; Berg, 1997; Morris & Bellon, 2004), and should lead to a specific local adaptation and intra-varietal diversity (Berg, 1997).

Participatory plant breeding (PPB) and participatory varietal selection (PVS) has been widely used on various crops in Africa. Scientists and farmers used PVS to identify preferred sweet potato varieties e.g., (Richard. W. Gibson et al., 2008; Kapinga et al., 1998), and PPB to lead to the official release of a new sweet potato variety called NASPOT 11(Richard. W. Gibson et al., 2011). More details on PPB and PVS can be found in (Sperling L, Ashby, Smith, Weltzien, & McGuire, 2001; Sperling L, M. E. Loevinsohn, & Ntabomvuras, 1993; Witcombe, Gyawali, Sunwar, Sthapit, & Joshi, 2005). PPB was also successfully used in bush beans in Rwanda (Sperling & Scheidegger, 1996) and in Honduras (Humphries, O. Gallardo, J. Jimenez, & F. Sierra, 2005), cassava production in Tanzania (De Waal, F. R. Chinjinga, L. Johansson, F. F. Kanju, & Nathaniels., 1997) and in Ghana to develop superior cassava cultivars (Manu-Aduening et al., 2006). On-farm participatory research has also been used in improving soil organic matter and soil nutrient management in southern Africa (Kanyama-Phiri, Snapp, Kamanga, & Wellard, 2000; Kerr, Snapp, Chiwa, Shumba, & Msachi, 2007; Snapp, Mafongoya, & Waddington, 1998; Snapp, Rohrbach, Simtowe, & Freeman, 2002). In most of these examples, the involvement of farmers in research helps scientists to consider other factors such as taste, color, and farmer preferences that would not have otherwise been considered in formal plant breeding.

Therefore, participatory research should be encouraged and used more often to help in advancing adapting technologies in smallholder farmers. This research approach will play a significant role in helping communities to adapt to the impacts of climate change on agriculture, especially for the most vulnerable communities. However, participatory research has some challenges such as high costs, some attributes such as taste and color may be hard to measure, and sometimes there is a need for additional training by scientists such as learning of farmers languages (Morris & Bellon, 2004). Some of these challenges can be addressed by working with scientists within the area who may know the local language and carefully planning the research process before actual implementation.

1.5.7 Conclusion

There is still a need to conduct more research on sweet potatoes in Uganda and in East Africa in general. This will not only help in reducing malnutrition problems experienced in the countries, but it will also prepare the country against the impacts of the projected changes in climate which are likely to affect many crops. From the characteristics of varieties discussed above, it is important to note that no single characteristic can be used to determine the best variety to select although such knowledge is useful in determining the potential and impact one variety might have over the other. For example, some people may prefer varieties with a sweet taste while others may be interested in early maturing varieties. Under such scenarios, the use of participatory research approaches is important in coming up with the best option. Equally important, is the involvement of governmental and community-based organizations, and research institutions that help in supporting the farmers. All the success stories of released varieties in Uganda have been attained as a result of a joint effort from all organizations.

Finally, as more growth characteristics become available for different varieties of sweet potato, there is need to carry out sweet potato modeling to assess the impact of changes in environmental conditions especially climate and management practices on sweet potato production. The information to be generated from modeling work will be highly valuable especially to the sweet potato breeders who normally take over 10 years of crop breeding before a new variety that can perform well in the changing environmental conditions is released.

1.6 Research gaps and limitations

This study made an attempt to address the following research gaps.

Agronomic data for sweet potatoes for the whole growing process from planting to harvesting was scarce. Therefore, experiments were set up in two growing seasons for four identified cultivars, two orange-fleshed (SPK 004 and NASPOT 10) and two non-orange fleshed cultivars (NASPOT 1 and NASPOT 11) in Uganda and the existing historical sweet potato data was supplemented with one collected from field plots.

Relevant data for climate impact assessments are scarce: detailed agronomic data for sweet potato cultivars grown in East Africa are limited; representative high-quality climate data for the region are scarce, and soils data is only available at coarse spatial resolution. suitable climate data source was identified to cater for the poor climate data characterized by missing records and soils data were also collected from both field plots and from existing historical soils databases. A number of gridded satellite climate data products were compared with the observed climate records which could be found in the three East African countries, Uganda, Kenya, and Tanzania.

Deterministic simulation models for sweet potatoes exist but are relatively young or still in development. A process-based crop model for sweet potatoes was non-existent and yet it was the suitable research tool required for this study. This study, therefore, modified, calibrated and used an existing crop model, with the consultation of the original model developer from India.

Relatively little is known about how climate influences sweet potato growth, development, and yield.

1.7 Research questions and objectives

The major objective of the research was to assess the impact of climate variability and change on sweet potato production in East Africa. The study addressed the following research questions and their corresponding objectives.

Question 1. What are major climatic constraints, currently and in the recent past, to sweet potato production in East Africa?

Objective 1: Develop a modeling framework for use in a deterministic sweet potato crop model, SPOTCOMS, for East Africa.

***Objective* 2:** Develop a historical climate and soils database for East Africa for the period 1980 – 2009.

Objective 3: With the SPOTCOMS crop model, identify the major climatic constraints for sweet potato production in East Africa.

Question 2. How might sweet potatoes be impacted by projected future changes in climate in East Africa?

Objective 4: Develop local climate change scenarios for East Africa for near-term future (2041-2070) and distant future (2071-2100) periods

Objective 5: Estimate the impact of projected future climate change on sweet potato production in the region

Question 3. Which areas are (historically and in the future) most suitable for sweet potato production in East Africa?

Objective 6: Identify areas most suitable for sweet potato production in East Africa using historical and future climate data

CHAPTER 2

APPLICATION OF A PROCESS- BASED MODEL FOR SWEET POTATO GROWTH DEVELOPMENT IN EAST AFRICA

2.1 Introduction

As one of the ten most important staples that the feed the world (FAO, 2014), sweet potato has not yet made significant progress in crop modeling research compared to maize, rice, wheat, and potatoes. Unlike most staples, however, sweet potato, especially the orange-fleshed cultivars, are very rich in vitamin A, and some have high amounts of calcium, iron, and zinc (Tumwegamire et al. 2011), stores well in soil as a famine reserve crop, is drought tolerant (Gomes & Carr, 2003), grows well in low-nutrient soils and can sustains families up to 6 months on a piece-meal harvesting. In areas with declining land availability, sweet potato is a valuable crop due to its relatively high production per unit area, multipurpose functions as both food and animal feed, and low input requirements (Bashaasha et al., 1995; Bovell-Benjamin, 2007; Diop, 1998; Jiang, Jianjun, & Wang, 2004). Sweet potato is also valuable crop in areas with declining land availability due to its relatively high production per unit area and low input requirements (Bashaasha et al., 1995; Bovell-Benjamin, 2007; Diop, 1998; Jiang et al., 2004).

East Africa was selected for this study owing to the high level of importance that sweet potato has in that region. Almost every community grows sweet potato for either home consumption only or for both home consumption and income generation. The household communities growing who grow sweet potatoes are largely the rural poor and therefore any intervention of improving production whether coming from government or research would be of great value to the people. There is limited application of fertilizer to the largely rain-fed sweet potato growing in East Africa. Usually, with limitations in land size, sweet potatoes are normally intercropped with beans and sometimes maize, but for better yields, agricultural systems in the crop are mono-cropped tend to do much better. The nutrition value and high production from sweet potato would help in improving the health and ensure food security among the communities.

One approach to performing such evaluations is to employ crop simulation models which provide researchers with an advantage of a more controlled assessment of weather and climate, soils, and/or other crop variables than field experiments. Existing sweet potato models include Sweet potato COMputer Simulation (SPOTCOMS, (Mithra & Somasundaram, 2008) a process-based model, CLICROP (Arndt, Farmer, Strzepek, & Thurlow, 2012) an empirical/statistical regression-based model, and an International model for policy analysis of agricultural commodities and trade (IMPACT) (Rosegrant et al., 2008) an economic-based model. Process-based models, however, have strengths and some limitations. For example, SPOTCOMs is based on the detailed representation of sweet potato growth and development processes and can be used for impact assessments at any location with some level of calibration, but many of the detailed input data and other information required by the model may be difficult to obtain. On the other hand, empirical models typically use climate-yield relationships and have an advantage over process-based simulation models as they may capture the effects of cultural and economic limiting factors on crop yields. The major drawback of statistical models is that they cannot be used in assessments under conditions that may lie outside of the empirical range of conditions the model was developed with.

The main objective of the present study was to develop a sweet potato modeling framework for Uganda using a process-based SPOTCOMS model. The main objective was achieved by determining the sweet potato cultivar parameters followed by a model calibration and validation process. The project was aimed at investigating the response and productivity of sweet potatoes under different environmental conditions. There is, therefore, a need to evaluate sweet potato production in order for communities to continue to benefit from the crop's roles and characteristics.

2.2 Materials and methods

2.2.1 Treatments and experimental design

A split-plot field design was used with four replications (Ekanayake, 1989). Genotypes were assigned randomly to main plots. Individual genotype plots were 14 m long and 2.7 m wide; rows were 1 m apart with 0.3 m within row planting distance. There were 14 rows in each plot. Non-rooted sweet potato apical stem cuttings of approximately 30 cm length were planted on ridges which were 1.0 m apart and at a plant-to-plant spacing of 30 cm. The cuttings were planted on 29 August 2012 and on June 15, 2013, for the first and second growing seasons respectively, and sampling began 17 days after planting and continued at 10 days' intervals until 28 January 2013 for the first season and November 14, 2013, for the first and second growing seasons. Figure 2.1 shows the design/layout of the plots and blocks.

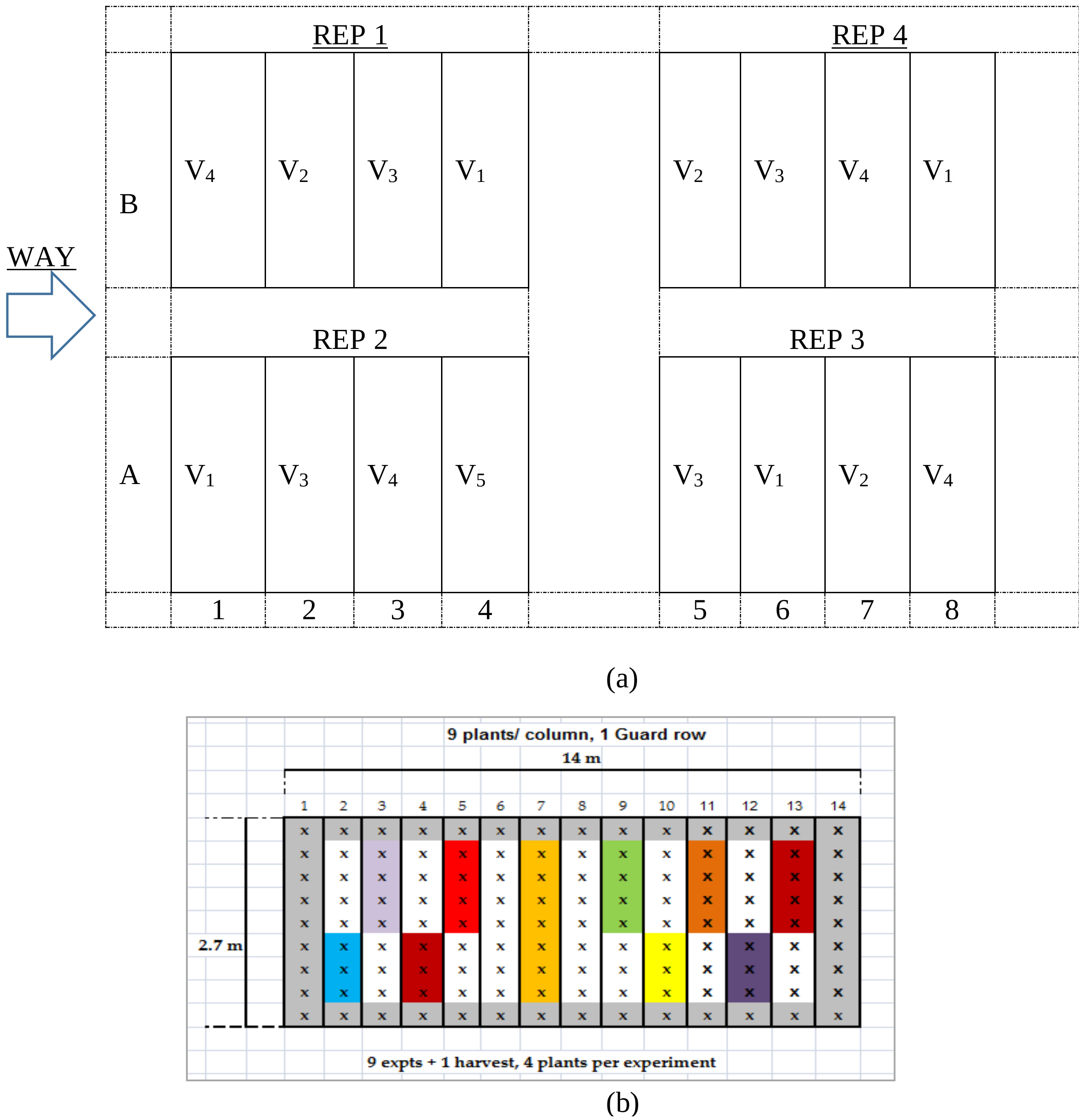


Figure 2. 1 Design of the experiment. (a) The layout of field plots by cultivar type, V1, V2, V3, V4 for the four replications; REP 1, REP 2, REP 3 AND REP 4. V1, V2, V3, V4 represent the sweet potato cultivars NASPOT 1, NASPOT 10 O, NASPOT 11 and SPK 004. (b) The layout of vines for a single cultivar plot. The crosses represent plants in a column and colors are used to only emphasize that 4 plants in the same column are sampled every sampling date.

2.2.2 Selection of cultivars

Orange-fleshed cultivars, NASPOT 10 O (Mwanga et al. 2009) and SPK 004 (Kakamega) (Mwanga et al., 2007) and non-orange fleshed cultivars, NASPOT 1(Gibson et al., 2008; Gibson et al., 2011) and NASPOT 11(Gibson et al., 2011) were planted in two seasons from August 29, 2012 to January 28, 2013 and June 15, 2013 to November 14, 2013. The four cultivars were selected for this study because of their popularity and competitive traits as shown in Table 2.1. For example, the two non-orange cultivars, NASPOT 1 AND NASPOT 11 are high yielding varieties, NASPOT 10 has a higher rate of maturity than all the rest, and SPK 004 has a high level of B-Carotene.

Table 2. 1 Properties of sweet potato cultivars used in this study

Cultivar trait	**Cultivars**			
	NASPOT 1[1,2,3,4]	**NASPOT 10**[3]	**NASPOT 11**[4]	**SPK OO4**[5, 6, 7, 8, 9, 10]
Root flesh color	Pale yellow	Dark orange	Cream	Orange
Maturity (days)	120-150	110	120-150	120-150
Average root yield (kg/ha)	29	16	28	14.9
B-Carotene (µg/100g)		185.6-342.8		376-760
Taste	Sweet	Moderately sweet	sweet	Moderately sweet
Resistance to Weevils	S	S	S	S
Resistance to SPVD	MR	MR	MR	MR
Resistance to Alternaria stem blight		MR		MR

[1]Mwanga et al., 2003a; [2]Gibson et al., 2008; [3]Mwanga et al., 2009; [4]Gibson et al., 2011; [5]Mwanga et al., 2005; [6]Yanggen and Nagujja, 2006; [7]Mwanga et al., 2007a; [8]Mwanga et al., 2007b; [9]Namanda et al., 2011; [10]Tumwegamire et al., 2011a

2.2.3 Plant management

A nursery bed for multiplying the sweet potato vines was set up earlier for the four cultivars from which vine cuttings were collected and used in the experimental plots. The four sweet potato cultivars were grown in field trials during the period 2011-2013 Namulonge, in Uganda. The field trials were monitored regularly and moderate irrigation was applied in case two weeks passed without the field went without receiving rainfall. Diammonium phosphate (DAP) was broadcasted on the mounds at earlier stages of planting sweet potato in order to boost the nitrogen and phosphorous levels in the soils. This was done in order to allow the sweet potatoes to grow under water-stress-free conditions.

2.2.4 Plant trait destructive monitoring

Alternate rows leaving border rows were sampled for non-destructive measurements for the three replicates. The fourth replicate was left undisturbed up to the end of the full maturity period in order to compare the root yields with the data which was being collected during destructive sampling. The phonological data that was collected from the field during the growing seasons included the following sweet potato attributes: vine length, number of leaves, leaf area, number and size of roots, fresh and dry weights of vine, leaves, and roots, canopy cover. The data were measured every 15 days, according to Kooman et al., (1996), as a part of the monitoring of the growth and development of the sweet potato crop.

2.2.5 Soils

The soils used in to run the model for Namulonge in 2012 and 2013 were analyzed before the experiments were set up to identify the soil classification, bulk density, PH and the nitrogen (N), phosphorous (P) and potassium (K). The actual concentrations of soils used in earlier experiments of 2004 to 2009 were not recorded and therefore an assumption has been taken to use the soil concentrations of 2012 as representative amounts. The soil classifications for the three locations were determined using the Harmonized World Soils Database (HWSD) version 1.2 (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). The HWSD is a 30 arc-second raster database with over 16000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1: 5,000,000 scale FAO-UNESCO Soil Map of the World.

Soil analysis tests were carried out on August 21, 2012, before preparing the land for the experiment. A 40 m^2 plot of land was sampled and was divided into two small plots of about 20 m^2. Two pits of about 2 m^2 wide and 1.5 m deep were dug in the middle of each plot. A number of soil properties including color, structure, consistency, porosity, depth, texture among others were described as shown in Tables 2.1 and 2.2. In addition, four soil samples (two from each plot) were sampled with the help of a post hole Auger. A transect was demarcated diagonally across the big plot and two spots were sampled within each small plot, these were mixed and quarter sampled to get a representative sample at both top (0-30 cm) and sub (30-60 cm) depths.

Generally, the entire plot was characterized by blackjack and *Conyza floribunda* as the dominant vegetation. The plot had been under fallow for about two years and the land was gently sloping towards the valley. The new formation and inclusions included evidence of mineralization. Table 2.3 shows the soil characteristics of the first pit and the second pit. The soil bulk density was 1.36 g cm^{-3} and the volumetric soil water content, at field capacity and wilting point, were 0.35 and 0.17 m^3 m^{-3} respectively. The pH of the soils was ranging from 3 to 5.5 which indicates acidic soils which are the preferred soils for sweet potato growth (Stoddard et al. 2013). The soil textural class also generally ranged from sand to loamy sand, the most suitable texture for sweet potato growth. The concentrations of nitrogen, phosphorous and potassium found in the soils were 79.13 kg/ha, 58.36 kg/ha, 90.19 kg/ha respectively. When compared to the required NPK concentration for optimum sweet potato growth which is 84.06 kg/ha, 224.17kg/ha, and 336.25 kg/ha, the soil was more deficient in phosphorous which are an essential element in the development of root biomass (Stoddard et al., 2013). Diammonium phosphate (DAP) fertilizer was, therefore, applied at a rate of 50 kg/ha, six weeks after planting the trial using soil nutrient recommendations for sweet potatoes (Stoddard, 2013). We could not apply the fertilizer at planting, which is the most suitable time because soil analysis results were not available at an earlier time. However, from the available literature, we feel that the fertilizer was still effective at six weeks after planting.

A description of the soil variables is very important in running SPOTCOMS crop model, especially the field capacity (FC), permanent wilting point (PWP) and albedo, as they are linked to the amount of water available for the crop and the amount solar radiation used in photosynthesis (Gijsman, Jagtap, & J.W., 2002). The number of nutrients in form of nitrogen (N), phosphorous (P) and potassium (K) present in the soil also directly influence the amount of crop yield got by the crop at the end of the growing season. Nitrogen aids in the development of aerial parts of sweet potato and an excess of it leads to increase in the number and size of leaves and rapid stem growth (Ustimenko and Bakumovsky, 1982). Potassium, on the other hand, increases the rate of photosynthesis and therefore affects the quantity of tuber yield (Biswas and Mukherjee, 1994).

Ref: Ustimenko, C.G.V. and Bakumovsky, 1982. Plants growing in the tropics and subtropics. Mir publishers.

Table 2. 2 Soil characteristics for Pit One

Property	Horizon A	Horizon B	Horizon C
Depth	0-20cm	20-50cm	50 and above
Boundary sharpness	Clear	Diffuse	Diffuse
Moisture	Very moist	Moist	Moist
Color	Reddish black	Dusky red	Dark reddish brown
Texture	Loam	Clay loam	Sandy clay loam
Structure: (a) Strength	Structureless	Weakly developed	Weakly developed
(b) Shape		Granular	Crumb
Consistency	Loose	Firm	Friable
Porosity	Fine porous	Fine porous	Fine porous
Fauna	None	None	None
Drainage	Perfect	Perfect	Imperfect
Compactness /Cementation	Loose	Firm	Friable
Root distribution (a) Size	Small	Small	Small
(b) Quantity	Frequent	Few	Few
(c) Shape	Free growing	Free growing	Free growing
(d) Nature	Fibrous	Fibrous	Fibrous
(e) Health	Alive	Alive	Alive
(f) Age	Young	Young	Young

Table 2. 3 Soil characteristics for Pit Two

Property	Horizon A	Horizon B
Depth	0-40cm	40 and above
Boundary sharpness	Diffuse	Diffuse
Moisture	Moist	Moist
Color	Dusky read	Dark reddish brown
Texture	Loam	Clay loam
Structure: (a) Strength	Weakly developed	Weak
(b) Shape	Granular	Crumb
Consistency	Friable	Extremely firm
Porosity	Fine	Fine
Compactness /Cementation	Loose	Very compact
Fauna	None	None
Drainage	Perfect	Imperfect
Root distribution (a) Size	Small	Small
(b) Quantity	Frequent	Few
(c) Shape	Free growing	Free growing
(d) Nature	Fibrous	Fibrous
(e) Health	Alive	Alive
(f) Age	Young	Young

Table 2. 4 Soil nutrient analysis results

Details	**pH**	**O.M**	**N**	**Av.P**	**K**	**Ca**	**Mg**	**Na**	**Textural %ages**			**Textural class**
		%ages		**mg/kg**	**C.moles/kg**				**Sand**	**Clay**	**Silt**	
Next to pit 1, Top (0-30cm)	5.1	2.1	0.1	0.8	0.7	5.9	2.1	0.11	56	27	17	Sandy clay loam
Next to pit 1, Sub (30-60cm)	4.9	0.8	0.0	0.4	0.7	4.7	1.4	0.1	38	51	11	Clay loam
Next to pit 2, Top (0-30cm)	5.0	2.1	0.1	1.3	0.6	6.9	2.7	0.1	56	26	18	Sandy loam
Next to pit 2, Sub (30-60cm)	5.0	1.5	0.1	0.3	0.7	5.6	1.9	0.2	39	48	13	Sandy clay
Critical levels	5.5	3.0	0.2	15.0	0.2	4.0	0.5	<1.0				

2.2.6 Secondary agronomic and climate data

The study also used secondary data collected from past field trials from five locations, Namulonge, Masaka, Serere, Soroti and Kabale all located in Uganda, and later used in crop model evaluation. The locations were strategically located across Uganda in regions with varying climates (Table 2.1) and they were the ones with historical agronomic data which also could limit the choice of site location. Out of the five locations, Kabale was the coolest and was also located at the highest elevation of 2,000 m. Serere was the hottest while the wettest and driest sites were Namulonge and Masaka respectively. The locations had slightly different soil textures at the top-soil and subsoil layers, varying bulk densities, and varying elevation. Historical data for climate and sweet potato root yield was collected from all the sites.

Table 2. 5 Description of experimental data sites used in the determination of cultivar coefficients and validation of the crop model

Site name	**Lat**	**Lon**	**Elevation (m)**	**Annual rainfall (mm)**	**Topsoil (0-30 cm)**						
					Texture classification	**Bulk Density (kg/dm3)**	**PH**	**Soil Base Saturation (%)**	**Fraction**		
									Silt	**Clay**	**Sand**
Kabale	-1.25	29.98	2,000	1,018	Clay (light)	1.34	5.3	59	16	47	37
Namulonge	0.53	32.62	1,160	1,242	Clay loam	1.36	5.5	65	24	31	45
Masaka	-0.30	31.67	1,310	1,200	Clay loam	1.36	5.5	65	24	31	45
Serere	1.49	33.46	1,085	1,250	Clay(light)	1.42	4.9	40	16	40	44
Soroti	1.72	33.62	1,100	1,365	Clay(light)	1.42	4.9	40	16	40	44
Site name	**Lat**	**Lon**	**Average min. temp. (^{0}C)**	**Average max. temp. (^{0}C)**	**Subsoil (30-100 cm)**						
					Texture Classification	Bulk Density	PH	Soil Base Saturation	Fraction		
									Silt	Clay	Sand
Kabale	-1.25	29.98	10	23	Clay (light)	1.34	5.3	44	14	54	32
Namulonge	0.53	32.62	16	28	Clay	1.43	5.4	69	21	45	34
Masaka	-0.30	31.67	17	28	Clay	1.43	5.4	69	21	45	34
Serere	1.49	33.46	18	31	Clay (light)	1.42	5.1	49	15	46	39
Soroti	1.72	33.62	13	28	Clay (light)	1.42	5.1	49	15	46	39

2.2.7 Trend analysis for the collected field data

Trend analysis was performed between seasons and among cultivars on the eight field variables including vine length, number of leaves, leaf area, number of branches, length of branches, and number of storage roots, fresh weight and dry weight of storage roots. Correlation analysis was performed between seasons and among the four cultivars using the formula:

$$r = \frac{\sum(xy)}{\sqrt{(x^2 + y^2)}} \qquad (1)$$

Where *r* is the correlation coefficient, *x* is the index time series during the season and *y* is the same variable in the second growing season for a similar cultivar or for any of the other three cultivars.

2.2.8 Calibration and validation of SPOTCOMS crop-model

2.2.8.1 The SPOTCOMS model

The present research used a process-based sweet potato model, SPOTCOMS (Sweet POTato COMputer Simulation) developed by (Mithra & Somasundaram, 2008). The model simulates phenological development in relation to photothermal time, net assimilation, resource allocation to different plant organs-below and above ground, transpiration, and soil water dynamics on a daily time step. The model simulates crop phenology as a function of growing degree days and divides sweet potato growth into three phases. That is, the first phase from planting to tuber initiation, middle phase from tuber initiation to the beginning of tuber bulking and the final phase from the beginning of tuber bulking to harvest (Mithra & Somasundaram, 2008). The parameters that drive the model were determined using eight equations, equation 1 to equation 8 shown below. Equation 1 defines the growth process sweet potatoes, equation 2 defines the growth stages of sweet potatoes, equation 3 describes the development of vines, equation 4 describes the development of roots (also defined as tubers in the equation), equation 5 defines branching of the crop, equation 6 specifies the number of leaves on a sweet potato plant and, equations 7 and 8 define the leaf area of sweet potatoes.

$$phsgdd = GDD_i \qquad (2)$$

Where: $GDD_d = \sum_{i=1}^{d} TMEAN_i - d \, X \, T_{Base}$

GDD is the growing degree days accumulated on the i^{th} day after planting (DAP), i = 28 days under tropical conditions

$TMEAN_i$ is the mean temperature on i^{th} DAP

$$phs2gdd = \nabla GDD_i \qquad (3)$$

Where *phs2gdd*The difference between 4 weeks and 7 weeks after planting

$$Vlen = \frac{VL_i}{GDD_i} \qquad (4)$$

Where VL_i is vine length on the i^{th} DAP and GDD_i is GDD on i^{th} DAP

$$tgrate = \frac{nTBR_i}{GDD_i} \qquad (5)$$

Where $nTBR_i$ is the number of tubers on i^{th} DAP

$$br_{gap} = BR_i \, X \, LF_i \qquad (6)$$

Where BR_i is the number of branches on i^{th} DAP and LF_i is the number of leaves on branches on i^{th} DAP

$$lfactor = \frac{LF_i}{GDD_i} \quad (7)$$

$$lafactor = \log(LF_i)\ X\ ALA_i \quad (8)$$

Where ALA_i is the average leaf area on i^{th} DAP

$$larea = Average\ leaf\ area \text{ for a cultivar for the whole growing season} \quad (9)$$

A few modifications were performed on the model in order to make it more robust and applicable to various parts of the world with limited climate data. The major modifications in the model included the removal of daily maximum and minimum humidity in the weather file and the new variable of daily insolation incident on a horizontal surface (in MJ/m^2/day) was included. The soil file required by the model requires the nitrogen (N), phosphorous (P) and potassium (K) concentrations found in the soil before planting and the amount added during the growing season as fertilizers. Four soils classifications were added to the existing four soil classifications. The added soil classes were loamy sandy, loam, sandy clay, and sandy clay loam while the original classes included sandy, sandy loam, clay loam, and clay. The soils used in SPOTCOMS are based on three variables namely field capacity (FC), permanent wilting point (PWP) and albedo. FC, the volumetric soil water content at drained upper limit in a soil layer (cm^3[water]/cm^3[soil]) and PWP, volumetric soil water content in a soil layer at lower limit (cm^3[water]/cm^3[soil]), were determined in accordance to (Saxton, Rawls, Romberer, & Papendick, 1986) and (Gijsman et al., 2002). Finally, the crop evaporation (ET_c) was modified by using the crop coefficients (K_c) reported at the initial, middle and end of the growing season in (R. G. Allen, Pereira, Raes, & Smith, 1998). The details of data used to run the model are discussed below.

The modifications made included, change of type of solar radiation data from sunshine hours to watts per square meter, the output of more variables such as potential evapotranspiration (PET), evapotranspiration of the crop (Et_c), and soil moisture or root available water (RAWtr). Also, in the second phase of sweet potato growth, the model assumes that a sweet potato plant has 1 storage root, that is, when the parameter, tgrate equals one, one storage root is produced and the second phase begins at the end of 2^{nd} week and ends at the end of 7th week. For phsgdd, the minimum temperature (Tmin) should be taken as 23^0C, maximum temperature (Tmax) as 32^0C and mean daily temperature (Tmean) as 27.5^0C for all locations in the tropics. Two parameters were added; R2R – the row to row spacing (100 cm) and P2P – the plant to plant spacing (30 cm). Table xxx shows the soil descriptions that the model currently has.

The initial conditions for SPOTCOMS model were:

- Optimum Temperature for Sweet potato=25.0 ^{0}C
- Base Temperature for Sweet potato=8.14 ^{0}C
- Maximum Temperature for Sweet potato=38.0 ^{0}C
- Leaf duration=47 days
- Extinction coefficient=0.8
- $PLMX_{optimum}$=45.0; $PLMX_{optimum}$ is the maximum photosynthetic efficiency at optimum temperature (Kg/ha/hr)
- Maintenance coefficient at 20 ^{0}C =0.01
- Initial level of water available in the soil=5.0 mm
- Root depth: 1.25 m

Table 2. 6 Soil characteristics used in SPOTCOMS

Soil type	Field capacity	Permanent wilting point	Albedo
Sandy	0.120	0.045	0.370
Sandy loam	0.230	0.110	0.250
Clay loam	0.335	0.205	0.215
Clay	0.360	0.220	0.140
Loamy sandy	0.161	0.059	0.300
Loamy	0.267	0.083	0.230
Sandy clay	0.333	0.195	0.255
Sandy clay loam	0.204	0.066	0.292

The model runs using a set of data inputs including weather data (minimum and maximum temperature, precipitation and solar irradiance), soil properties, and agronomic data. The weather data used consisted of daily rainfall for the period 2004 to 2013 reported at the weather stations of Namulonge and Soroti. Due to the lack of a data at Serere, and since the distance between Serere and Soroti is only 25km, the rainfall data from Soroti was used as a representative precipitation for Serere. Due to the absence of data at weather stations in the study sites, daily minimum temperatures, maximum temperatures, and solar radiation were provided by the National Aeronautics and Space Administration -Prediction Of Worldwide Energy Resource (NASA-POWER, 2014) for the period 2004-2013. The selection of this dataset was also justified by previous work which showed that solar radiation data from this source were often much better than station data (J. W. White, Hoogenboom, Wilkens, Stackhouse Jr, & Hoel, 2011).

SPOTCOMS estimates the effect of potassium stress on tuber yield using Mitscherlich's equation (Biswas and Mukherjee, 1994):

$$TBR_K = 1 - 10^{-C_K K} \quad (10)$$

where: i

TBR_K =Potassium stress on tuber production,

C_K = Constant,

K=Quantity of K applied (Kg/ha).

Nitrogen stress on mean tuber weight is estimated in SPOTCOMs using Mitscherlich's equation (Biswas and Mukherjee, 1994):

$$TWT_N = 1 - 10^{-C_N N} \quad (11)$$

where: i

TWT_N =Potassium stress on tuber production,

C_N = Constant,

N=Quantity of N applied (Kg/ha).

One major limitation of SPOTCOMS model was its lack of sensitivity and failure to terminate when the temperature exceeds 38^0C, the maximum temperature for sweet potato growth. In case a location had temperatures greater then 38^0C, the warmest locations had to be removed. Luckily enough, for this study, no location had temperatures exceeding 38^0C.

2.2.8.2 Determination of cultivar parameters for SPOTCOMS

In order to determine the cultivar parameters required in running the model, sweet potato trials were set up at Namulonge Crops Resources Research Institute (NaCRRI) in Uganda using a complete randomized block design for two growing seasons, August 2012 - February 2013 and July 2013 - December 2013. The second growing season trial was exactly the same design as the first trial consisting of four sweet potato cultivars, NASPOT 1, NASPT 10 O, NASPOT 11 and Kakamega (SPK004). For each experimental trial, we set up four replications for each cultivar, three of which were used for taking measurements of four selected sweet potato plants using destructive sampling during the growing season and the fourth was left undisturbed until the final harvesting at maturity. In both experiment trials for the two seasons, irrigation, a herbicide, and Diammonium phosphate fertilizer were applied to ensure that the crop grows without in non-limiting conditions. The plant attributes measured and recorded in the trials included the length of stems, number of roots, number of leaves, leaf area, number of branches, the wet and dry weight of roots, the wet and dry weight of stems and wet and dry weight of leaves. The data used to evaluate the performance of the model was taken from root yield data that was reported from field trials conducted at Namulonge, Serere and Soroti for the seasons shown in Table 1 for the period 2004 to 2009 under rainfed conditions (Mwanga et al., 2007) (Mwanga et al., 2010). Calibrating the model under non-limiting conditions is a recommended procedure which enables the model to accurately simulate crop yield under rain-fed conditions (Ruiz-Noguera, Boote, & Sau, 2001).

2.2.8.3 Calibration and testing of SPOTCOMS

Calibration and testing of SPOTCOMS were performed using data sets from the two experiments of 2012 and 2013 growing seasons which had observations of the phenology of sweet potatoes. The datasets from previous experiments were conducted under rainfed conditions and recorded root yield, biomass and vine yield at harvest and therefore were not suitable candidates for calibration. In the determination of suitable crop parameters to use in the model, the average of plant attributes was determined from four combinations of replications and was then used to determine crop parameters using equations 1, 2, 3, ..., 8. The combinations only considered three replications, the fourth replication was to be used for model testing and verification only and did not undergo destructive sampling during the growing season. The four combinations included: replication1 and 2 (Rep 1&2); replications 1 and 3 (Rep 1&3); replications 2 and 3 (Rep 2&3);

and replications 1, 2 and 3 (Rep1,2&3). The computed sets of parameters were then used to run the model separately and root yields of simulated results for the four cultivars were evaluated using a descriptive statistical assessment between the observed root yields recorded from the fourth replication in the two seasons for the four sweet potato cultivars. The purpose of this assessment was to select a combination of parameters which provided the best fit of simulated root yield to the observed values. The combination with the best fit was used to run rest of model simulations used to evaluate the performance of the model using rainfed root yield data. Moreover, since all the four combinations of crop parameters were actually determined from the field data and therefore considered legitimate values for crop parameters, they were all ranked and the maximum and minimum values formed the range for specific sweet potato parameters. This information was considered useful for future scientists who would be interested in understanding or investigating the limits to which a specific parameter can be changed.

2.2.8.4 Sensitivity analysis of cultivar coefficients in SPOTCOMS

The purpose of the performing sensitivity analysis on cultivar coefficients was to generate output variability associated with the variability of input, and also to assign the simulated output variability to the model coefficients that affect it most (Pathak, Fraisse, Jones, Messina, & Hoogenboom, 2007; Ruget, Brisson, Delécolle, & Faivre, 2002). Local sensitivity was used to provide a normalized measure in the comparing all model coefficients derived in section 2.3.4.1a. Local sensitivity was determined for model responses using the base and the +/-5% changes in the base value. The relative change in output and the change in parameter was used to calculate the sensitivity indices. All the eight coefficients determined were individually used to determine the sensitivity indices using the equation proposed by (Pathak et al., 2007) below.

$$\beta\left(\frac{Y}{\theta}\right) = \frac{(Y-Y_i)/_Y}{(\beta-\beta_i)/_\beta} \tag{12}$$

Where *i* represent individual coefficients: phsgdd, phs2gdd, Vlen, tgrate, br_{gap}, lfactor, lafactor, or larea. Y is simulated storage root yield using the initial set of determined coefficients and Y_i is the simulated storage root yield obtained for each level of an individual model parameter (β_i) while keeping all other model parameters at their base values.

2.2.8.5 Evaluation of model performance

The purpose of model evaluation in this section was to assess the performance of the model for sweet potatoes grown under rainfed conditions. This was an important step because sweet potatoes in Uganda is largely grown under rainfed conditions (Ddumba, Andresen, & Snapp, 2014). A description of the locations used in the present study was presented in Table 1. In both model testing and evaluation, seven descriptive statistical parameters were used. The coefficient of determination (R^2) is the second order of the Pearson correlation coefficient which explains the extent of agreement between the simulated and observed values (an R^2 equal to 1shows a very strong agreement and 0, a very week agreement). The slope of regression, *a*, was used to describe the relative systematic error in the simulated yields (an *a* equal to 1 is an optimal value). The present study hypothesized that there should be an agreement between model-simulated root yield and the observed root yield for a specific cultivar shown by a slope of regression *a* greater than zero and approaches 1 for optimal model fit to the observed values. The mean bias error (MBE) which is an indicator of the average systematic error as described in (Davies & McKay, 1989) was determined. The mean absolute bias error (MABE) defined as the average of absolute differences between simulated and observed values (ranges from 1 to infinity) and is used to calculate the average magnitude of simulated errors, irrespective of their direction was determined according to (Shaeffer, 1980). The root mean square error (RMSE) that describes the average absolute deviation between the simulated and modeled values and the index of agreement (IA) – (Willmott & Wicks, 1980) were determined. The IA is a standardized measure of the degree of model simulation error and proportionality between predictions and observations with a range of 0 to 1, where an IA closer to 1 indicates higher simulation agreement and an IA equal to 0 indicates no agreement at all. IA is more consistent than the linear correlation coefficient, but sensitive to extreme values, due to the squared differences. Finally, the modeling efficiency (ME) according to (Nash & Sutcliffe, 1970) was determined. ME is a normalized measure of the relative magnitude of the data variance compared with the residual variance (noise). An ME equal to 1 is an optimal value or perfect fit, an ME equal to 0 means simulated values are as accurate as the mean of the observed data, and negative values mean that simulated values are worse than the mean of observed data. The corresponding equations of the described statistics are shown in equations 10 to 15.

$$y = ax + b + e \qquad (13)$$

Where y is the simulated yield, a the slope of the regression line, x the observed root yield, b the intercept and e the error of simulation,

Ho: a<0, the null hypothesis

H1: a ≥ 0, our research hypothesis, if a is significant, then there is an agreement between simulated root yield and observed root yield

$$\text{MBE} = \frac{\sum_{i=1}^{n}(s_i - O_i)}{n} \qquad (14)$$

$$\text{MABE} = \frac{\sum_{i=1}^{n}|S_i - O_i|}{n} \quad (15)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{n}} \quad (16)$$

$$\text{IA} = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(|S_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (17)$$

$$\text{ME} = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (18)$$

Where Oi and Si are observed and simulated values respectively, n is the number of samples and $\bar{O}$ is the mean of the observed values. Data analyses were performed using SYSTAT software (Systat Software Inc, 2007).

2.3 Results

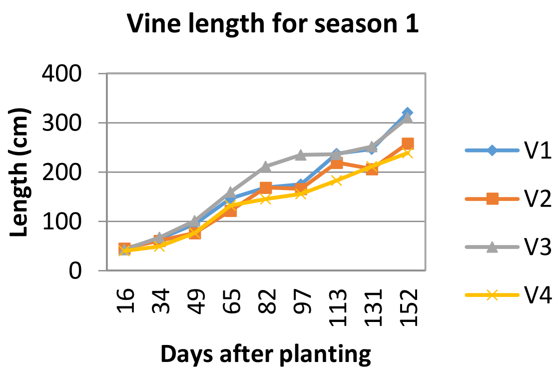
2.3.1 Variation of Sweet potato data from the field

Analysis trends of plant attributes such as length of vines and number of storage roots for the entire growing season were consistent with the growth of plants, as we expected the plant to increase in biomass with an increase in days after planting (Figures 2.2 to Figure 2.7). SPK004 had the longest vine length followed by NASPOT 1, while NASPOT 10 and NASPOT 11 lengths were similar (Figure 2.2). The vine length between the two seasons was very similar although season 1 length was a slightly longer. The correlation coefficients indicated that the vine lengths between cultivars and seasons were similar.

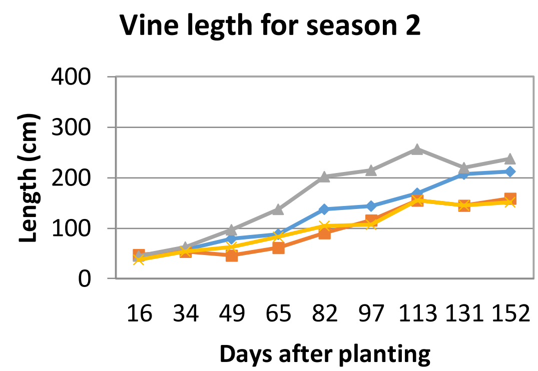
The number of leaves for different cultivars across the two growing seasons varied similarly over the growing season (Figure 2.4). However, SPK004, which had the longest vine length, has a little bigger number of leaves. There were high correlations of vines between cultivars across different seasons (Figure 2.4). Leaf area was one of the major variables that distinguished between cultivars. Each cultivar had a different size with SPK004 having the smallest size of leaves and NASPOT 10 0 had the largest size of leaves. This pattern is consistent between the two growing seasons.

The graphs for number of branches showed varying numbers of branches over the growing season (Figure 2.3). However, since during the sweet potato crop was just in the early stages of growth, the number of branches towards harvest should be the ones that are representative of the actual number of branches. Therefore, NASPOT 10 0 was the one cultivar that showed a consistent number of branches of 6 in both seasons. The other 3 cultivars showed an average of 4 branches in the first growing season and 6 branches in the second season.

At harvest, the number of storage roots recorded in season one was 3,4,5,6 for NASPOT1, SPK004, NASPOT 11, and NASPOT10 0 respectively while the number recorded in season 2 was 3 for NASPOT 11 and 4 for NASPOT 10 0, SPK004 and NASPOT 1 (Figure 2.5). The cultivars showed a high relationship between each other with the magnitude of 0.8. The flesh and dry weights of cultivars in seasons at harvest were double those of the second season (Figure 2.6 and Figure 2.7). The cultivars in the first season had 3 kg/plant, 4kg/plant and 6 kg/plant for NASPOT1, SPK004 and the two cultivars (NASPOT 11 and NASPOT10 0) respectively. The dry weights were almost similar for like cultivars I the two growing seasons. The correlations were high for among cultivars and between seasons.



(a)

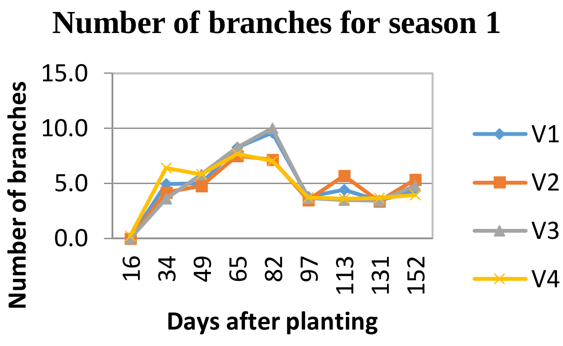


(b)

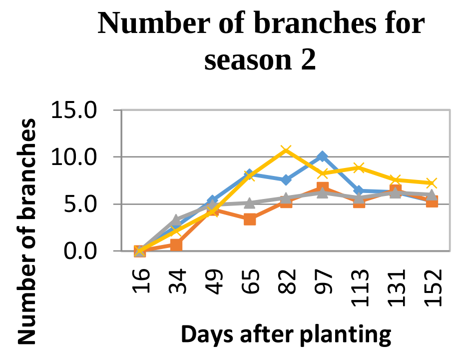
Correlations		Season 2			
		V1	V2	V3	V4
Season 1	V1	0.97	0.94	0.92	0.96
	V2	0.97	0.96	0.96	0.98
	V3	0.96	0.92	0.96	0.95
	V4	0.98	0.93	0.94	0.96

(c)

Figure 2. 2 Vine length:V1 = NASPOT 1, V2 = NASPOT 10 0, V3 = SPK004 (Ejumula), V4 = NASPOT 11



(a)

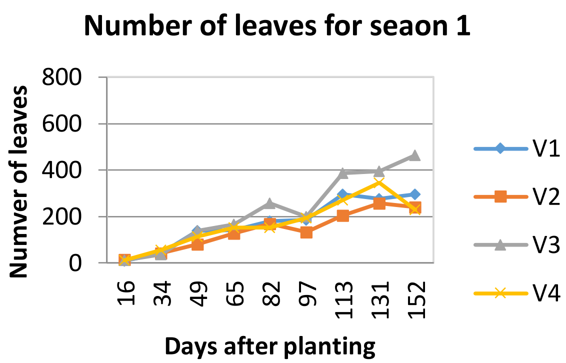


(b)

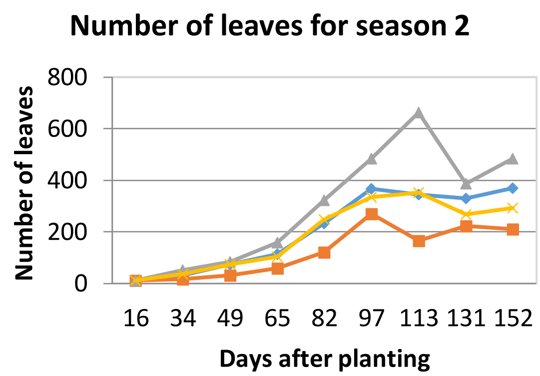
Correlations		Season 2			
Branches		V1	V2	V3	V4
Season 1	V1	0.59	0.29	0.54	0.66
	V2	0.64	0.40	0.67	0.74
	V3	0.60	0.35	0.55	0.66
	V4	0.48	0.14	0.47	0.43

(c)

Figure 2. 3 Number of branches:.V1 = NASPOT 1, V2 = NASPOT 10 0, V3 = SPK004 (Ejumula), V4 = NASPOT 11



(a)

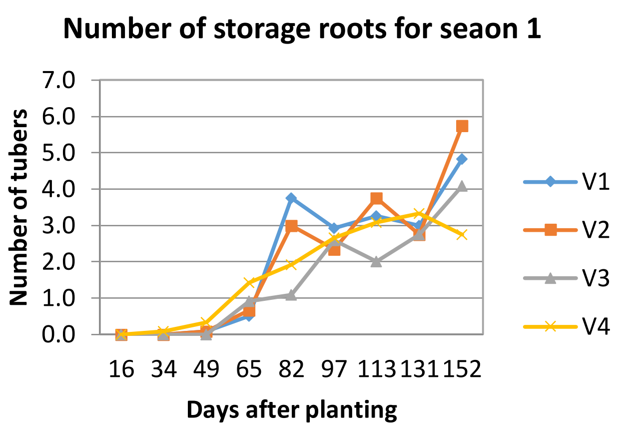


(b)

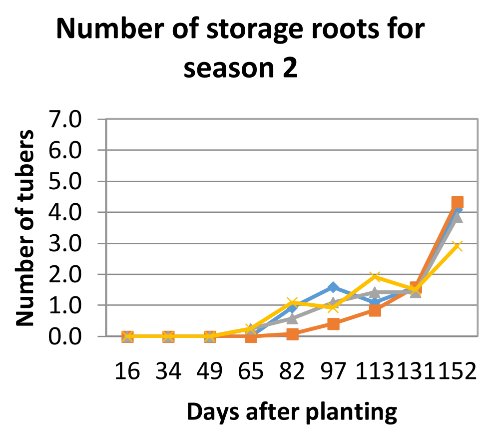
Correlations for leaves		Season 2 V1	V2	V3	V4
Season 1	V1	0.91	0.80	0.89	0.88
	V2	0.88	0.79	0.81	0.83
	V3	0.88	0.77	0.85	0.84
	V4	0.86	0.81	0.82	0.83

(c)

Figure 2. 4 Number of leaves and leaf arear: V1 = NASPOT 1, V2 = NASPOT 10 0, V3 = SPK004 (Ejumula), V4 = NASPOT 11



(a)

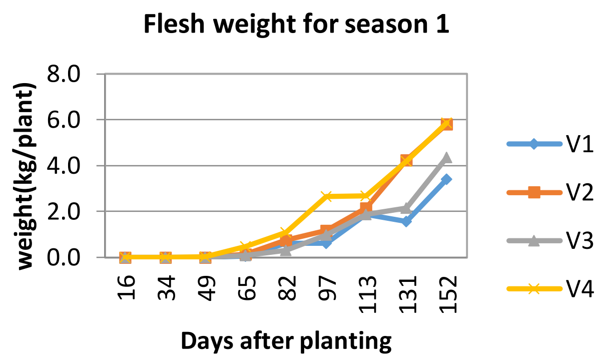


(b)

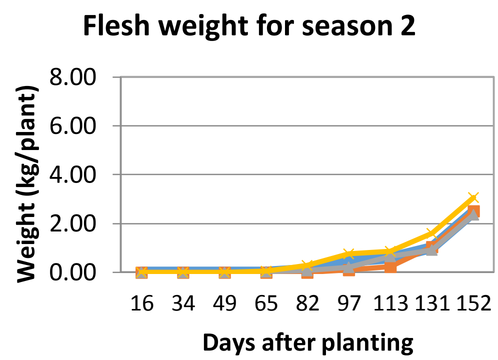
Correlations		Season 2			
		V1	V2	V3	V4
Season 1	V1	0.86	0.70	0.83	0.92
	V2	0.91	0.82	0.92	0.99
	V3	0.93	0.85	0.93	0.91
	V4	0.69	0.56	0.70	0.83

(c)

Figure 2. 5 Number of tubers: (a) season 1; (b) season 2; (c) Spearman's correlation coefficients. V1 = NASPOT 1, V2 = NASPOT 10 0, V3 = SPK004 (Ejumula), V4 = NASPOT 11



(a)



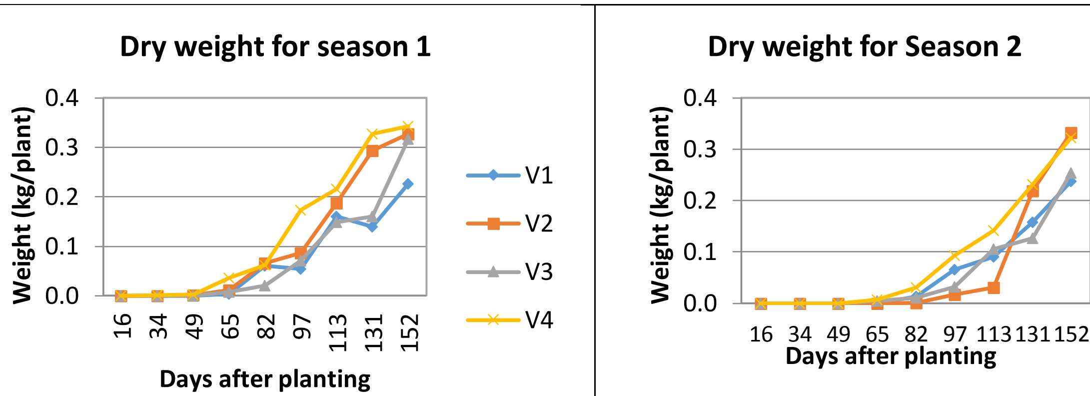
(b)

Correlations

Flesh weight		Season 2			
		V1	V2	V3	V4
Season 1	V1	0.95	0.90	0.96	0.96
	V2	0.96	0.94	0.95	0.98
	V3	0.98	0.94	0.98	0.99
	V4	0.94	0.88	0.92	0.97

(c)

Figure 2. 6 Flesh weights, and correlation coefficients for storage roots. V1 = NASPOT 1, V2 = NASPOT 10 0, V3 = SPK004 (Ejumula), V4 = NASPOT 11



(a) (b)

Correlations Dry weight		Season 2			
		V1	V2	V3	V4
Season 1	V1	0.94	0.83	0.95	0.95
	V2	0.97	0.91	0.94	0.98
	V3	0.98	0.92	1.00	0.98
	V4	0.96	0.86	0.91	0.97

(f)

Figure 2. 7 Dry wieghts and correlation coefficients for storage roots. V1 = NASPOT 1, V2 = NASPOT 10 0, V3 = SPK004 (Ejumula), V4 = NASPOT 11

2.3.2 Cultivar coefficients

Mean cultivar coefficients were computed for replication are shown in Table 25. For each cultivar, the cultivar coefficients were determined from three replications and the fourth replication was used as a control replication. Using the different combinations of one pair of replications, a number of cultivar coefficients were determined from which a mean coefficient and the maximum and minimum values were also determined. On plotting the range of the different coefficients,

Figure 2.8 shows that the coefficient which is a function of vine length (vlen) had the biggest range for all cultivars while lafactor and laarea, both of which are function of leaf area had the largest variation between different cultivars.

Table 2. 7 Summary of cultivar parameters determined from field experiments

Summary of cultivar coefficients	**vlen**	**tgrate**	**br_gap**	**lfactor**	**lafactor**	**larea**
NASPOT 1 (V1)						
Mean	0.12484	0.01094	0.00226	0.15377	100.3	46.4
Minimum	0.09138	0.00736	0.00150	0.14440	94.4	44.0
Maximum	0.16501	0.01473	0.00265	0.16976	109.4	49.9
NASPOT 11 (V2)						
Mean	0.09776	0.01237	0.00246	0.09453	104.4	51.0
Minimum	0.06388	0.00920	0.00225	0.00955	97.8	48.6
Maximum	0.12911	0.01595	0.00280	0.11750	113.4	54.6
SPK 004 (Kakamega) (V3)						
Mean	0.12784	0.00972	0.00245	0.21925	54.8	24.2
Minimum	0.10241	0.00614	0.00180	0.20702	45.9	20.5
Maximum	0.16848	0.01289	0.00303	0.22553	64.8	27.8
NASPOT 10 (V4)						
Mean	0.09115	0.00696	0.00253	0.12020	75.3	35.2
Minimum	0.06553	0.00614	0.00182	0.11135	70.7	33.3
Maximum	0.13615	0.00767	0.00353	0.14837	80.6	37.3

For all cultivars, phsgdd = 543.2, phs2gdd = 407.4, P2P = 0.3 m, R2R = 1 m

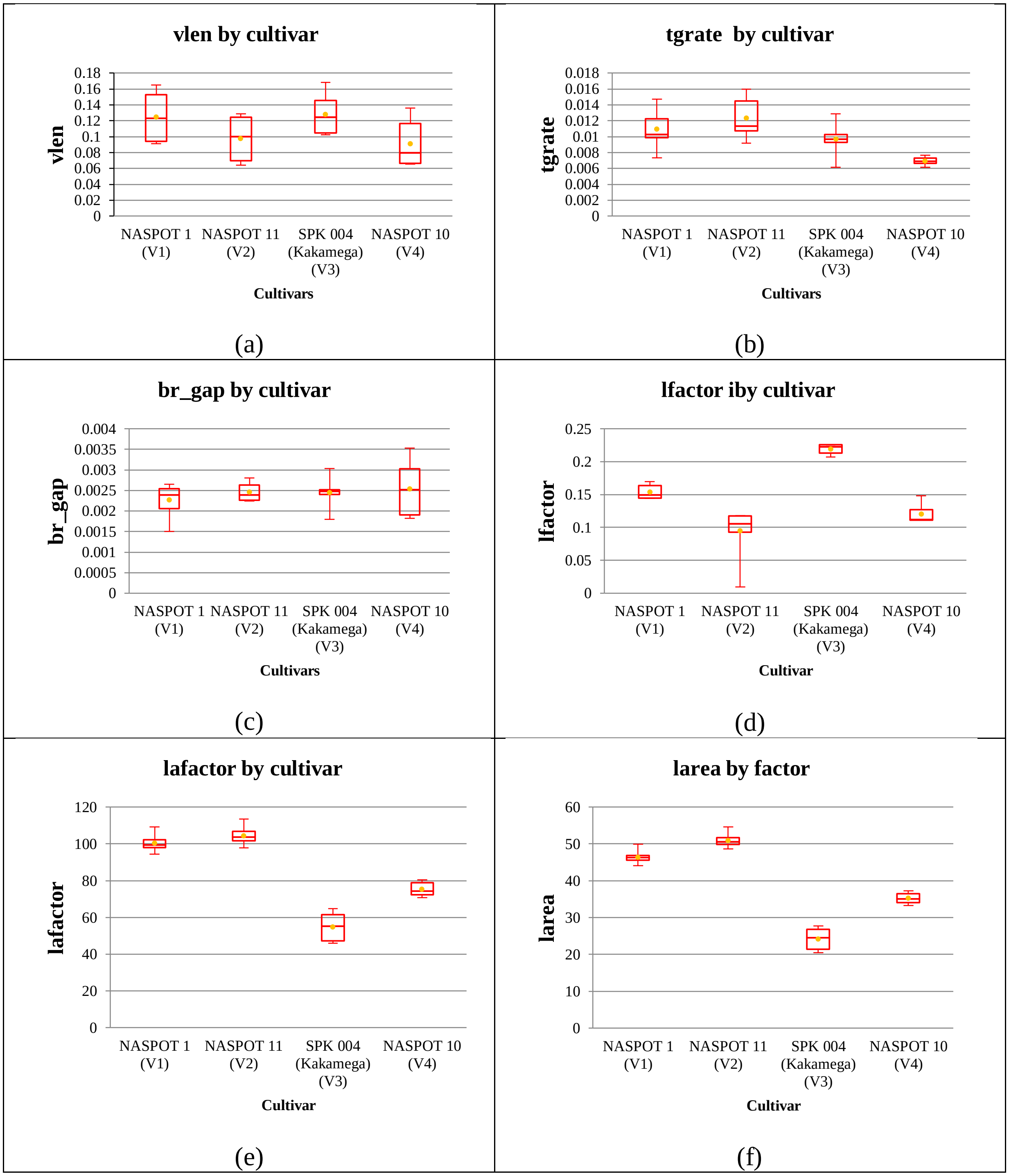


Figure 2. 8 Range of cultivar parameters in 2012 and 2013 season. The orange dot represents the mean of simulated root yield

2.3.3 Sensitivity of cultivar coefficients from field data

With reference to the average sensitivity function, results of the sensitivity analysis of cultivars indicated that the coefficients which are a function of growing degree days, phsgdd, phs2gdd were the most sensitive for all the four cultivars (Table 2.8). On considering other coefficients that are cultivar specific, the most sensitive cultivar coefficients were tgrate for both NASPOT11 and NASPOT1, vlen and br_gap for SPK004, and vlen and lafactor for NASPOT 10 0. Figure 2.9 shows the sensitivity of the cultivars which was determined by taking the average of all individual cultivars. The graph emphasizes the earlier observed trends of phs2gdd being the most sensitivity with a negative effect while larea was the most sensitive when considering other coefficients with the exception of those which are a function of growing degree days.

Table 2. 8 Sensitivity analysis of cultivar coefficients

Coefficie-nts	**Optimum coefficients Rep 2&3_sn1**	**5% increase of the parameter**	**Simulated yield sn1**	**β_5% increase**	**5% decrease of the parameter**	**Simulated yield sn1**	**β_5% decrease**	**Av β**
NASPOT 1 (V1)								
phsgdd	543.2	570.36	39.6	-2.35	516.04	41.6	1.44	**-0.45**
phs2gdd	407.4	427.77	39.4	-2.43	387.03	42.2	1.19	**-0.62**
vlen	0.1514	0.15897	39.4	-2.43	0.14383	39.6	2.32	-0.06
tgrate	0.00736	0.007728	39.7	-2.28	0.006992	39.1	2.55	**0.13**
br_gap	0.0015	0.001575	39.5	-2.38	0.001425	39.4	2.43	0.02
lfactor	0.144397	0.151617	39.5	-2.40	0.137178	39.5	2.40	0.00
lafactor	100.23	105.2415	39.4	-2.42	95.2185	39.6	2.36	-0.03
larea	46.68	49.014	39.5	-2.41	44.346	39.6	2.36	-0.02
Simulated yield	44.9							
NASPOT 11 (V2)								
Coefficient	**Optimum coefficients Rep 2&3_sn1**	**5% increase of parameter**	**Simulated yield sn1**	**β**	**5% decrease of parameter**	**Simulated yield sn1**	**β_5% decrease**	**Av β**
phsgdd	543.2	570.36	43.7	-2.08	516.04	45.5	1.37	**-0.36**
phs2gdd	407.4	427.77	43.8	-2.03	387.03	47.2	0.66	**-0.68**
vlen	0.12911	0.13556	44.0	-1.94	0.12265	44.1	1.91	-0.01
tgrate	0.01595	0.01674	44.2	-1.87	0.015152	43.9	2.01	**0.07**
br_gap	0.0027	0.002835	44.1	-1.92	0.002565	44.1	1.92	0.00
lfactor	0.11750	0.12337	44.0	-1.94	0.11162	44.1	1.91	-0.02
lafactor	101.84	106.932	44.1	-1.94	96.748	44.0	1.96	0.01
larea	49.4	51.87	44.0	-1.96	46.93	44.1	1.93	-0.02
Simulated yield	48.8							

Table 2.8 (Cont'd)

SPK 004 (Kakamega)								
Coefficient	**Optimum coefficients Rep 2&3_sn1**	**5% increase of parameter**	**Simulated yield sn1**	**β**	**5% decrease of parameter**	**Simulated yield sn1**	**β_5% decrease**	**Av β**
phsgdd	543.2	570.36	35.5	-0.56	516.04	35.9	0.37	-0.10
phs2gdd	407.4	427.77	37.6	0.58	387.03	38.5	-1.07	**-0.25**
vlen	0.14035	0.14737	33.9	-1.45	0.13333	38.4	-1.01	**-1.23**
tgrate	0.00614	0.006447	36.6	0.01	0.005833	36.5	0.02	0.02
br_gap	0.0018	0.00189	34.9	-0.93	0.00171	35.5	0.60	**-0.17**
lfactor	0.225527	0.23680	35.2	-0.74	0.214251	35.4	0.63	-0.05
lafactor	46.17	48.4785	37.4	0.45	43.8615	35.7	0.49	0.47
larea	20.97	22.0185	36.4	-0.07	19.9215	34.1	1.34	0.63
Simulated yield	36.6							
NASPOT 10								
	Optimum coefficients Rep 2&3_sn1	**5% increase of parameter**	**Simulated yield sn1**	**β**	**5% decrease of parameter**	**Simulated yield sn1**	**β_5% decrease**	**Av β**
phsgdd	543.2	570.36	40.7	-1.02	516.04	43.2	-0.16	**-0.59**
phs2gdd	407.4	427.77	40.6	-1.05	387.03	43.4	-0.24	**-0.65**
vlen	0.13615	0.142958	40.7	-1.01	0.12934	42.9	0.00	**-0.51**
tgrate	0.00644	0.006762	41.2	-0.77	0.006118	40.6	1.04	0.13
br_gap	0.0019	0.001995	40.8	-0.94	0.001805	40.7	1.00	0.03
lfactor	0.111346	0.11691	40.6	-1.04	0.10578	40.5	1.09	0.02
lafactor	72.53	76.1565	40.7	-1.00	68.9035	42.8	0.02	**-0.49**
larea	34.06	35.763	42.6	-0.10	32.357	41.0	0.86	0.38
Simulated yield	42.9							

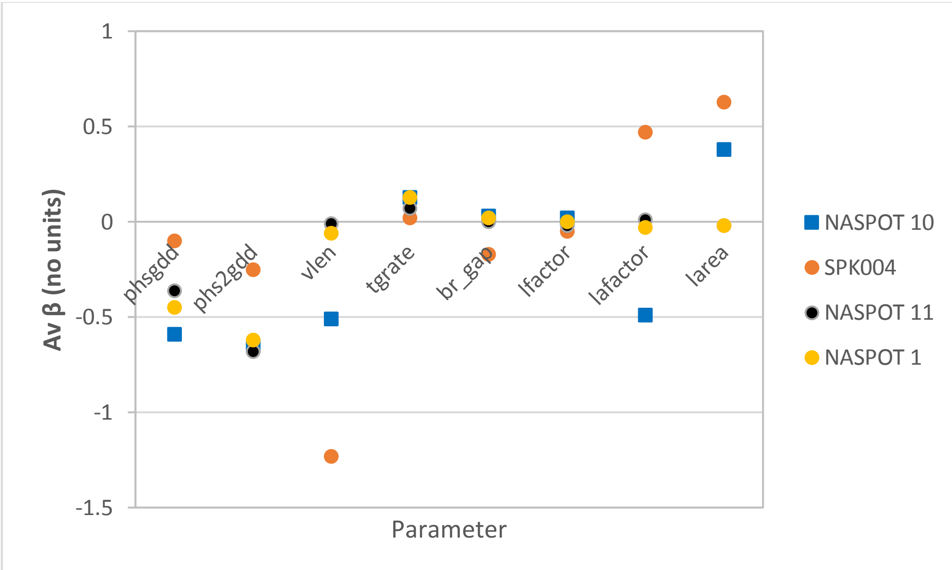


Figure 2. 9 Sensitivity analysis of cultivar coefficients

2.3.4 Calibration of the model

The experiment results presented here were for only 7 out 8 records corresponding to the four cultivars that were grown in two seasons. One record was removed for the second season for NASPOT11 because it had an unrealistic value which was extremely large and therefore could have been erroneously measured. The results from the seven data points of the field trial data are shown in Table 2.7.

Table 2. 9 Calibration (under irrigation) and evaluation

Sweet potato coefficients	n	MBE (t/ha)	MABE (t/ha)	R2	RMSE	IA	ME	a	p-value
Experimental results from irrigated field trials	7	1.16	2.58	0.418	3.18	0.940	0.901	0.894	0.001
Number of branches	7	0.4	0.9	0.52	1.2	0.74	0.13	0.757	0.029
Number of leaves	7	202.6	223.5	0.21	263.8	0.37	-8.87	0.901	0.384
Number of storage roots	7	0.3	1.5	0.28	2.1	0.33	-0.09	0.331	0.398
Rain-fed historical root yield	32	0.5	8.1	0.2444	9.6	0.70	0.31	0.3097	0.041

Table 2. 10 Correlation coefficients between simulated root yield and observed root yield at selected locations.

Location	Correlation Coefficient
Namulonge	0.68
Serere	0.55
Soroti	0.44
Masaka	0.67
Kabaale	0.48

In Figure 2.10, we compared the model simulated variables with data collected from actual field plots in order to examine the performance of the model. The model performed well in simulating the root yield of NASPOT 1, NASPOT 10 O and Kakamega-SPK004 since these values are very close to the 1:1 line but the model overestimates the root yield for NASPOT 11 (Figure 2.10a). The model is able to reconstruct the branching for the four cultivars pretty well although it slightly overestimates the number of branching for NASPOT 1 and NASPOT 11 (Figure 2.10b). Please note the values shown in these graphs are averages and therefore some of them are fractions.

The biggest weakness of the model was in reconstructing the number of leaves for the four cultivars. Figure 2.8c shows that the model underestimated the number of leaves for all the cultivars. This, therefore, means that our model parameter equations for leaves need further agronomic experiments in order to make the necessary modifications in the model. However, this drawback is not of a big concern for sweet potato modeling in East Africa because in this region mostly root tubers are consumed by humans and leaves are fed to animals. In Figure 2.10c, it can be observed that the model performs well in simulating the number of root tubers for three cultivars; NASPOT 1, NASPOT 10 O and Kakamega-SPK004. The model, however, simulates a slight underestimate of the number of root tubers for NASPOT 11.

Results from the model evaluation using 32 historical rain-fed sweet potato field data points are summarized in Table 2.7. The regression between simulated and observed historical yield data showed a significant relationship at the 95% level of significance. The mean bias error (MBE) was 0.5t/ha, the mean absolute bias error (MABE) was found to be 8.1 t/ha, the index of agreement was 0.7 and the modeling efficiency was 31%. In Figure 2.11a and b, the observed sweet potato points were plotted on a scatter plot in order to identify any relationships that could exist. The data points were organized by location and by cultivar (Figure 2.11 a, b) and another scatter plot did not represent any specific cultivar or location (Figure 2.11c). The figures show that data was generally distributed across the 1:1 line for all the locations except for Soroti. The cultivar-type scatter plot showed an even distribution of crop yields on the 1:1 line.

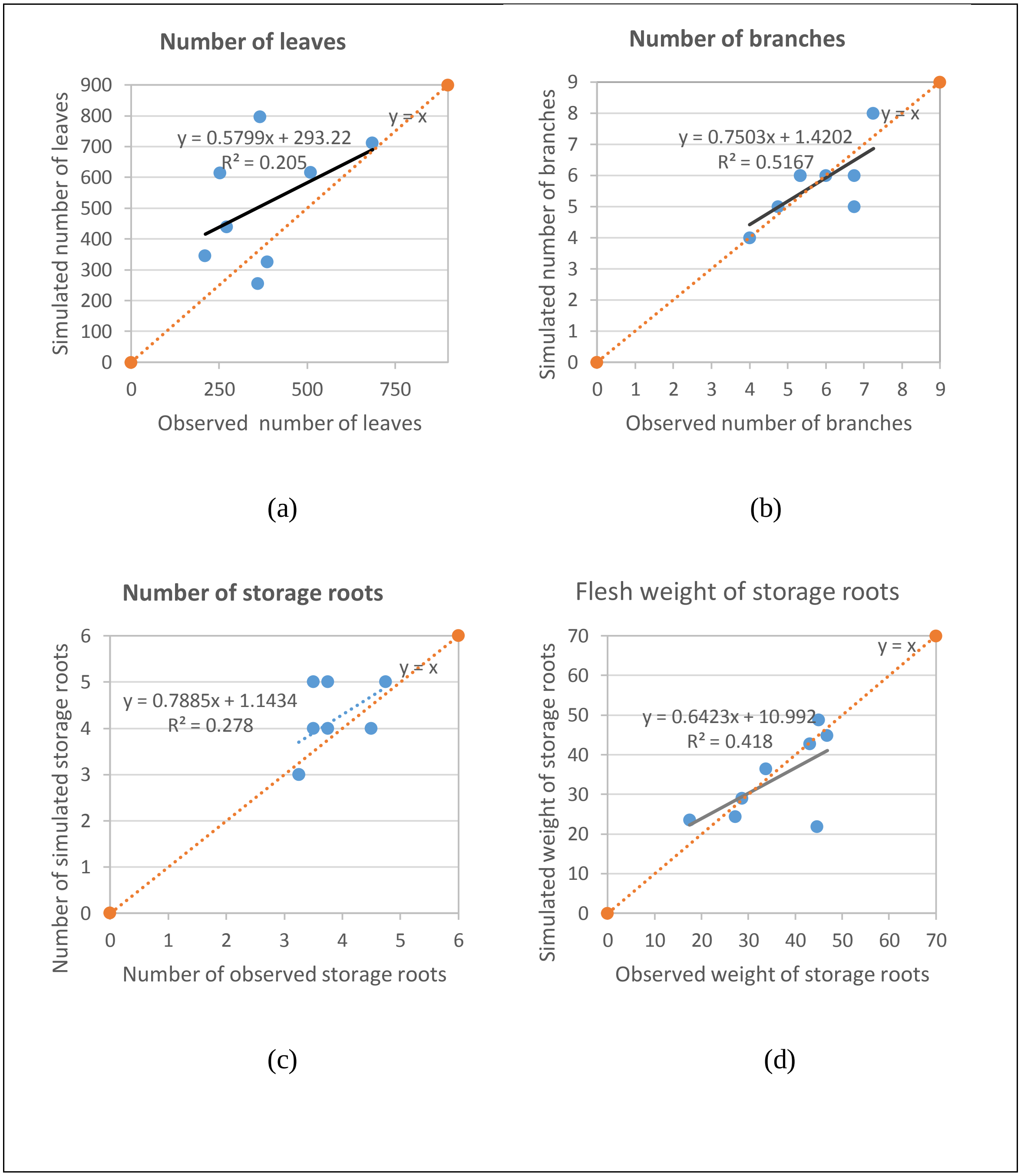


Figure 2. 10 Graphs of simulated against observed data

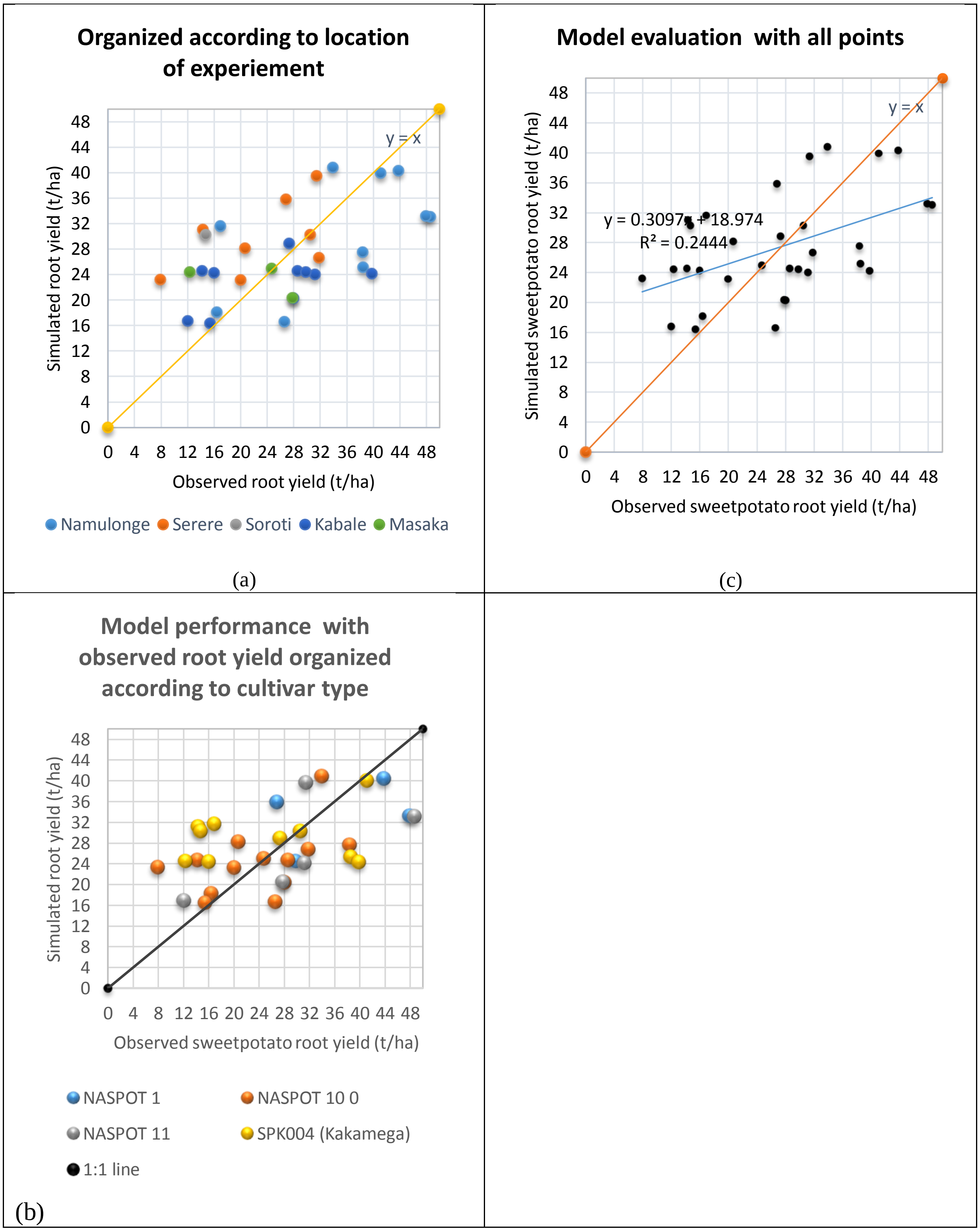


Figure 2. 11 Regression plot for model results using historical sweet potato yields for the period 2004-2009

2.4 Discussion

The differences were reported for different measured variables from the field trials were largely between the two seasons and to a lesser extent among cultivars within the same season. One major factor that changed between the two seasons was the amount of precipitation received. In the second season, received less precipitation than the second season. And even if irrigation was available in both seasons, there could have been a possibility that the timing of irrigation in the less wet season could not be applied at that exact time when water was most needed for. It was interesting to observe the differences in the physical attributes of the four cultivars. For example, the leaf area and vine length were the two most distinct features between cultivars, especially with SPK004 having very long stems and very little leaves.

The cultivar coefficients determined in this study were quite distinct among the four cultivars especially the ones that were unique to a particular cultivar namely vlen, tgrate, br_gap, lfactor, lafactor, and larea. A comparison of these coefficients with those obtained by (Somasundaram & Mithra, 2008) showed that only "tgrate" and "vlen" were within close range with the Indian cultivars, Sree Arum, Sree Bhadra, and Sree Rethna. This implies that cultivars from different locations had similarities because they were all sweet potatoes although there could be one or more features that made a particular cultivar able to grow in a particular environment. Also, the range of values of coefficients determined reported in this present study will be useful in future studies especially when researchers will be interested in establishing the maximum values to which the coefficients can be extended. This kind of information can be useful in the investigation of a drought tolerant crop or any other crop characteristics of that may be of interest.

Results from model calibration and evaluation are very promising. SPOTCOMS did very well in simulating sweet potato root yields. The model evaluation results were also within a decent range compared to other similar studies using crop models. However, on comparing the model results with other variables such as the number of leaves, the number of branches and number of storage roots, SPOTCOMS showed the largest weakness in simulating the number of leaves (Figure 2.8). Also, when we looked at the internal processes of the model such as the way the model handles the actual evapotranspiration and the readily available water, we noticed that the model was not responding as it would be expected.

The root mean square error (RMSE) of 3.18 t/ha for storage root yield simulated that was achieved in this study falls within the range of RMSE reported in previous studies which reported 2.88 – 3.42 t/ha in SPOTCOMS {Mithra, 2008 #23} and 1.14 – 4.17 t/ha in MADHURAM {Somasundaram, 2008 #21} in India. For the rest of the other crop variables, the modified SPOTCOMS in this study either fell below or above the range of values reported in the two previous studies. For example, this study reported an RMSE of 1.2 branches for the number of branches, 263.8 leaves for number of leaves, and 9.6 root tubers for the number of root tubers while previous studies by Somasundaram (2008) and Mithra and Somasundaram (2008) reported ranges of 3.53 – 6.91 branches, 5.51 – 15.93 leaves and 0.97 – 1.67 tubers. It was noted that whereas the model has some level of accuracy especially in simulating root yield, SPOTCOMS still needed to be improved in order to capture the growth process of sweet potatoes in East Africa.

A comparison with other crop models for potatoes and yam which are sister crops to sweet potatoes indicated varying ranges or RMSE for the root tuber yield but still falling within the RMSE values obtained in this study. For studies involving potatoes, Lenz-Wiedemann et al., (2009) reported an RMSE of 1.6t/ha using DANUBIA model, Angulo et al., (2013) reported a range of 1.13 – 2.65 t/ha when working with LINTULS-FAST model, while other studies reported 6.74t/ha, 8.7t/ha, 0.74 – 1.48 t/ha and 1.08 – 1.19 t/ha for the models REGCROP (Gobin, 2010), Potato Calculator (Jamiesen et al., 2009), SOLANUM (Condori et al., 2010), and LINTUL-NPOTATO (van Delden et al., 2001) respectively. In two studies involving the use of crop models for yam, the RMSE reported for CROPSYSTVB-Yam (Marcos et al., 2011) and EPIC-Yam (Srivastava and Gaiser, 2010) were 0.5 t/ha and 8.78 – 25 t/ha. All these values as reported from previous studies were not so unique compared to our value of 3.18 t/ha.

Another major limitation of SPOTCOMs was that the model continued to run normally even at high temperatures exceeding the maximum temperature of 38^0C above which sweet potato growth is expected to be inhibited. For many crops, increases in maximum temperatures severely lead to a reduction in yield and failure of reproductive processes (Thorntorn et al., 2014). For instance, yield reduction of 1.7% was reported when each degree day was spent above the maximum temperature under drought conditions in maize (Lobell et al. 2011). In another study involving rice production, rice yields reduced by 90% when the temperature was increased to 32^0C during the night compared with 27^0C (Mohammed & Tarpley, 2009). At the time of the study, the solution to increased temperatures beyond threshold values was to carefully assess the growing season temperatures at the location and ensure that locations which temperatures above that threshold value were not used for running the model.

2.5. Conclusion

Overall, our sweet potato model, SPOTCOMS, performed well in reconstructing the growth of the sweet potatoes cultivars. Second, the East African region now has the first calibrated sweet potato process-based model, having all the required parameters and coefficients for four sweet potato cultivars, which can be used in any form of impact assessment studies. Third, our experimental trials involved correction of various types of sweet potato growth data that is readily available for future reference and studies by any interested scientist. There is currently no comprehensive dataset like the one we collected from our first season and from the soon to be completed second season experiment.

One of the major achievements of this study is the determination of the sweet potato crop coefficients required for running SPOTCOMS model. The field experiments conducted at Namulonge across the two seasons in 2012 and 2013 provided the required dataset on the growth of sweet potato that made it possible to determine the coefficients. Whereas this was done at only one location under two seasons, it is recommended that follow-up studies be conducted across the whole East Africa region for many more sweet potato cultivars including the four cultivars used in this study. One major advantage or value that this study has attempted to achieve was the use of four representative high yielding cultivars, two of which were non-orange cultivars (NASPOT 1 and NASPOT 11) and the other two were orange cultivars (NASPOT 10 0 and SPK004-Kakamega). The other contribution of this study was the modification of the previous SPOTCOMS model to be able to input weather data of any size for any number of years and some other minor additions of variable outputs such as the potential evapotranspiration (ET), actual evapotranspiration (Etc) and the root available water (rwtr). These modifications imply that SPOTCOMS can now be run for a single site for multiple seasons.

The model was tested across Uganda in over four locations with varying climate and altitude. It should be noted that sweet potato cultivar coefficients were determined using two seasons at a single location in Uganda following minimum crop model requirements as suggested by (Boote et al 2009). This study is the first process-based study on sweet potatoes on the African continent and provides the foundation upon which subsequent studies can refer in order to continue with sweet potato modeling in the region. The sensitivity and range of the crop cultivar coefficients were determined in this study and therefore provides a good basis for similar modeling work in other regions with varying climates. The cultivar coefficient sensitivity analysis is also useful for studies which may be focusing on identifying a suitable cultivar for a given question of interest. For example, in (Pathak et al., 2007), a similar sensitivity analysis was performed on cotton crop in order to determine an ideal cultivar that would give high yields under a highly variable climate.

The performance of SPOTCOMS under the model evaluation results also showed that the model has a high potential in simulating sweet potato production in the region. This shows a lot of promise in the application of the model in answering various questions such as those associated with the effect of temperature, rainfall, and soils on the growth of sweet potatoes. Moreover, the model can now be used for investigating the impact of climate change on sweet potato production in the East African region, as will be demonstrated in the later chapter. The results from model evaluation also demonstrated that the model would be a good tool in studies involving various sweet potato cultivars as was shown on the four cultivars used in this study.

Like most models, SPOTCOMS has some limitations that will require to be addressed in future studies. For example, SPOTCOMS needs to be set such that it has a threshold beyond which if the temperature is exceeded, sweet potato growth would be inhibited. This has not yet been set in the model and therefore, the researcher is mandated to manually remove or not to consider locations with high temperatures exceeding 38^0C, the maximum temperature for sweet potato growth. Second, although the model is sensitive to both temperatures and soil moisture, SPOTCOMS did not appear to give a corresponding sensitivity on the actual evapotranspiration. In other words, in a case where the ETc would be elevated, the model did not show a corresponding variation in the root available water. This is one major area that requires revisiting in the model. Third, SPOTCOMS does not yet consider CO2 intake which is known to equally affect sweet potato growth just like temperature and soil moisture. Fourth, the model does not account for the effects of weeds, pest, and diseases and therefore, the model normally tends to overestimate yield because of this weakness. Finally, the model currently uses basic soil routines and does not account for the variation of soil nutrients in the various soil profiles as has been significantly developed in other crop models such as the DSSAT crop models (J. W. Jones et al., 2003). This too will have to be worked on in the future. One major shortcoming for SPOTCOMS, which is not uncommon in another process-based crop model, is that the model does not consider the effect of pests and diseases. This, therefore, means that the assumption is made that pest and disease management was carefully implemented in the fields, although this is not normally the case in reality.

CHAPTER 3.

THE IMPACT OF CLIMATE CHANGE AND VARIABILITY ON SWEET POTATO PRODUCTION IN EAST AFRICA

3.1 Introduction

Climate change is a critical global environmental challenge affecting various ecosystem services (Bage, 2007) leading to extreme weather events such as droughts, floods, erratic and unreliable rainfall. Rural agriculture-based livelihood systems that are already vulnerable to climate variability and change face immediate risk of increased crop failure, new patterns of pests and diseases, reduction in water and pasture availability, lack of appropriate seeds and planting material, and loss of livestock. This has led to a reduction in agricultural yields and worsening food insecurity (Parry et al., 2005; IPCC, 2007). These challenges were, in part, the motivation behind selecting East Africa for this study and the need to calibrate a sweet potato model for the region which would consequently be used to quantify the impact of climate change on sweet potato production and for other application in future research.

Like most regions of the world, East Africa faces unprecedented challenges due to climate variability and change. The region's temperature is projected to increase from 1.5^0C in the next 20 years to 4.30C by 2080 (Hepworth and Goulden, 2008) leading to changes in the ecosystem functioning. This will, in turn, lead to changes in the distribution of agro-ecological zones and soil moisture, and shortening of the growing seasons (Hulme, 1996). C3 plants such as roots and tubers will be the most preferred to C4 plants such as cereals whose yields especially for maize will be greatly reduced.

Luckily enough, roots crops such as sweet potatoes, are grown in most parts of East Africa and it is an important staple in most countries of this region. Sweet potato is among the four most important staple crops (FAO, 2012) in East Africa. Sweet potato is suited in ensuring food security and fighting poverty because of its efficient production of calories per unit land, even under low rainfall, poor soil fertility conditions and projected shortened growing seasons where other crops may fail. Furthermore, because of their high carbohydrate content, they have the potential to be transformed from purely subsistence food crops to industrial and commercial crops as has been achieved in Brazil and Thailand.

Potential effects of climate change on root crops production are difficult to assess not only because of the uncertainties of the magnitude of the changes in climatic variable but also due to uncertainties on how the crops respond to weather and climate, soil, management and other related factors. Sweet potato is known to be drought resistant and able to do well under marginal conditions. Unfortunately, there is little information on how well sweet potato performs, and for support farming communities under situations of extreme weather events, such as drought and shortened growing seasons.

This study was aimed at understanding the nature of climate change and variability in East Africa and how it impacts sweet potato production. The specific objectives of this study were threefold: To analyze the trends in the historical climate and sweet potato production across the East African region; To perform a sensitivity analysis on temperature and water requirements of sweet potatoes, and To assess the impact of climate change and variability on sweet potato production across East Africa.

3.2 Methodology

The steps followed to conduct research under Chapter three are shown in the flowchart in Figure 3.1. First, an extensive literature review on Global Circulation Models (GCMs) from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (Taylor, Stouffer, & Meehl, 2009) was conducted in order to identify models which were performing better in reconstructing Africa's climate. This review led to identifying four GCMs and two representative concentration pathways (RCP 4.5 and RCP 8.5). Climate data from the GCMs were downscaled by use of a weather generator, MarkSim and daily climate records for projected future climate and current climate where organized. This climate data and other data sets were then used as input datasets in a sweet potato model, SPOTCOMs to generate a simulation of sweet potato data which was then used to assess the impact of climate change and variability on sweet potato production on historical, current and projected future timescales. The details of the analysis methods were discussed in the subsequent sections.

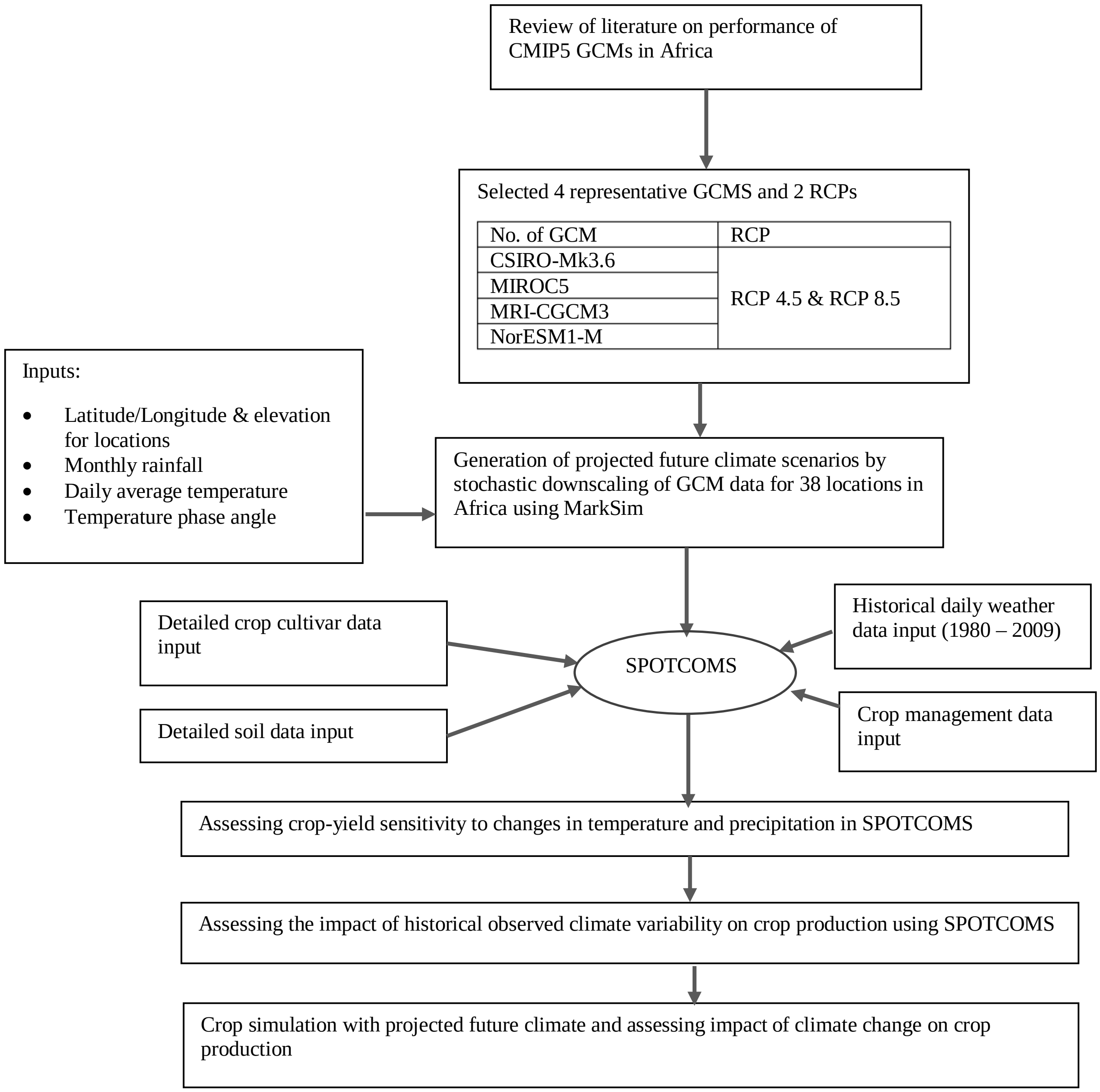


Figure 3. 1 Flowchart describing major project objectives, tasks, processes, and input data types

3.2.1 Description of the study area

The topography of East Africa varies from 0 m on the coast of the Indian Ocean to 5, 890 m at the highest peak of Mt. Kilimanjaro. The regional climate is controlled by the presence of the Intertropical Convergence Zone; Indian Ocean; Variable topography (Ogallo, 1989; Goddard and Graham, 1999; Anyah et al., 2006). The East African climate is also controlled by local features such as Lake Victoria, other smaller lakes and topographic features including large mountains like Mt. Kilimanjaro in Tanzania and Mt. Rwenzori in Uganda. The region receives a bimodal annual rainfall ranging between 500 mm to over 2,500 mm (FEWSNet, 2010, 2012) and mean annual temperatures range between 8.10C (at high elevations) to 320C (FEWSNet, 2010, 2012). Due to the favorable climate and good soils, agriculture is a major economic activity in the region and it sustains the majority of the population in the region.

3.2.2 Data sources

3.2.2.1 Historical data

The study used observed daily precipitation data for 13 sites in Uganda, 12 sites in Kenya and monthly precipitation data for 12 sites from Tanzania, for 1980-2009 as shown in Figure 3.2. These sites were strategically located in their respective countries and provide a nationwide representation of the different climatological zones. In order to have data for other locations of the study region, gridded precipitation datasets from sources that use non-tradition methods including remote sensing were compared with observed data from sites shown in Figure 2 in order to determine suitability to include in the study. The targeted gridded datasets evaluated included; CHIRPS dataset (Funk et al., 2013) with a 0.0250 and 0.050 resolution, NASA-POWER (NASA, 2013) dataset with a 10 resolution and AgMIP Coordinated Climate-Crop Modeling Project (C3MP) data (Ruane et al., 2015). The NASA-POWER and the C3MP gridded datasets had daily precipitation, daily maximum and minimum temperature and solar radiation while the CHIRPS dataset only had daily rainfall. From the analysis, the C3MP daily dataset was selected because it better captures rainfall distribution and actual sequence of extreme events than other data products (Ruane et al., 2015).

The AgMIP Coordinated Climate-Crop Modeling Project (C3MP) data is a historical (1980-2010) climate series from a bias-shifted version of the NASA Modern Era Retrospective-analysis for Research and Applications (MERRA; (Rienecker et al., 2011)) dataset. These s-ERRA data (Ruane, Goldberg, & Chryssanthacopoulos, 2015) are based on the MERRA and MERRA-Land (Reichle et al., 2011) outputs and are shifted to eliminate apparent monthly biases in comparison to an ensemble of gridded observational data from weather stations and satellites. These s-MERRA climate series also incorporate the NASA-GEWEX Solar Radiation Budget daily radiation data (Jeffrey W. White, Hoogenboom, Stackhouse Jr, & Hoell, 2008; Y. Zhang, Rossow, & Stackhouse, 2007).

The soils used in this study were provided by the harmonized world soils database (HWSD). The HWSD is a 30 arc-second raster database with over 16000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO, 2012). The resulting raster database consists of 21600 rows and 43200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). Reliability of the information contained in the database is variable: the parts of the database that still make use of the Soil Map of the World such as North America, Australia, West Africa and South Asia are considered less reliable, while most of the areas covered by SOTER databases are considered to have the highest reliability

(Central and Southern Africa, Latin America and the Caribbean, Central and Eastern Europe). Tables 3.1, 3.2, and 3.3, in the appendix, show that basic information about the study sites including the average rainfall, average temperature, and the soil characteristics.

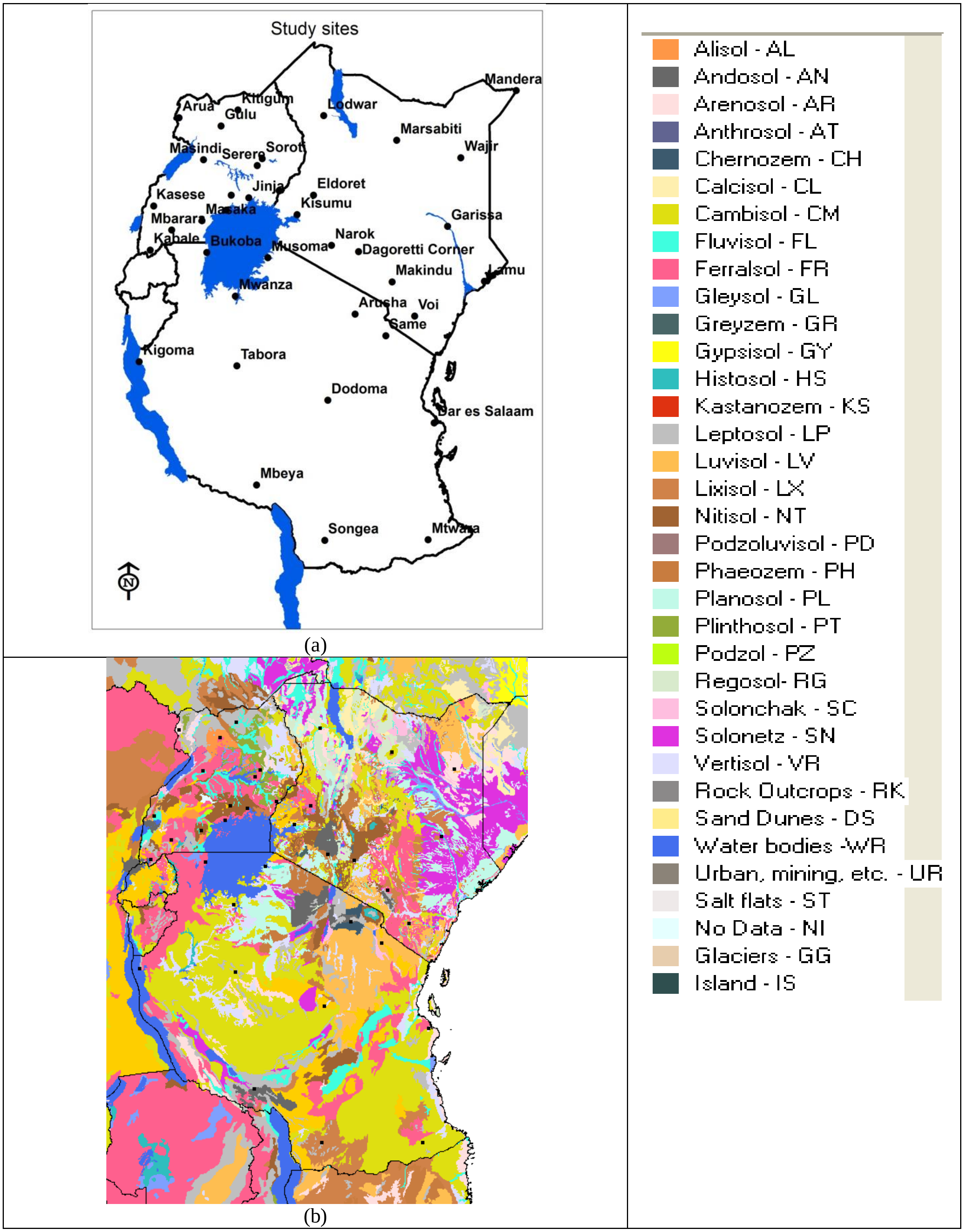


Figure 3. 2 Study area. (a) Locations of study sites, (b) soil map of Africa (source: FAO, 2012)

Table 3. 1 Basic Descriptions for the locations in Uganda

No.	Name of location	Average rainfall (mm)			Average Tmin (^{O}C)			Average Tmax (^{O}C)			Average Tmean (^{O}C)			Soil texture
		Annual (mm)	FMAMJ (mm)	ASOND (mm)	Annual Tmin (^{O}C)	Tmin FMAMJ (^{O}C)	Tmin ASOND (^{O}C)	Av. Annual Tmax (^{O}C)	Av. Seasonal Tmax: FMAMJ (^{O}C)	Av. Seasonal Tmax: ASOND (^{O}C)	Av. Annual Tmean (^{O}C)	Av. Seasonal Tmean: FMAMJ (^{O}C)	Av. Seasonal Tmean: ASOND (^{O}C)	
1	Gulu	1379	561	650	18.0	18.5	17.7	30.9	31.5	30.5	24.5	25.0	24.1	Clay (light)
2	Jinja	1370	645	583	16.3	16.8	16.0	27.6	27.7	27.5	21.9	22.2	21.7	Clay loam
3	Kasese	968	390	521	19.0	19.1	19.0	29.7	30.0	29.5	24.4	24.5	24.3	Loam
4	Kabale	1232	516	618	12.0	12.3	11.9	24.4	24.3	24.5	18.2	18.3	18.2	Clay (light)
5	Kitgum	1117	471	483	18.4	19.2	17.8	32.5	33.1	32.0	25.4	26.1	24.9	Sandy clay
6	Mbarara	990	376	549	14.7	14.9	14.7	27.8	27.8	27.8	21.2	21.4	21.2	Sandy clay
7	Masindi	1214	478	615	18.7	19.0	18.6	29.6	30.0	29.0	24.2	24.5	23.8	Clay (light)
8	Serere	1294	597	573	19.3	19.9	19.0	30.5	30.9	30.1	24.9	25.4	24.6	Clay (light)
9	Soroti	1250	565	549	19.9	20.4	19.6	30.7	31.0	30.4	25.3	25.7	25.0	Clay (light)
10	Tororo	1616	768	682	16.8	17.3	16.5	28.9	29.1	28.8	22.9	23.2	22.6	Sandy loam
11	Masaka	1214	592	527	16.4	16.6	16.5	27.0	27.1	26.9	21.7	21.8	21.7	Clay loam
12	Entebbe	1354	670	563	18.4	18.8	18.2	27.1	27.3	27.0	22.8	23.1	22.6	Clay (light)
13	Arua	1285	455	661	18.6	19.1	18.2	30.2	30.8	29.5	24.4	24.9	23.9	Sand
14	Namulonge	1259	539	601	17.2	17.6	16.8	28.5	28.6	28.4	22.8	23.1	22.6	Clay loam

Table 3. 2 Basic Descriptions for the locations in Kenya

No.	Name of location	Average rainfall (mm)			Average Tmin (^{O}C)			Average Tmax (^{O}C)			Average Tmean (^{O}C)			Soil texture
		Annual (mm)	FMAMJ (mm)	ASOND (mm)	Annual Tmin (^{O}C)	Tmin FMAMJ (^{O}C)	Tmin ASOND (^{O}C)	Av. Annual Tmax (^{O}C)	Av. Seasonal Tmax: FMAMJ (^{O}C)	Av. Seasonal Tmax: ASOND (^{O}C)	Av. Annual Tmean (^{O}C)	Av. Seasonal Tmean: FMAMJ (^{O}C)	Av. Seasonal Tmean: ASOND (^{O}C)	
1	Dagoretti Corner	892	496	311	14.0	14.6	13.9	26.9	27.2	27.0	20.5	20.9	20.5	Clay (heavy)
2	Eldoret	1091	475	419	11.5	11.8	11.2	25.3	26.1	24.7	18.4	18.9	18.0	Clay (heavy)
3	Garissa	347	134	187	23.0	23.7	22.6	34.9	35.7	34.4	28.9	29.7	28.5	Clay (heavy)
4	Kisumu	1494	724	588	17.8	18.3	17.5	29.4	29.6	29.4	23.6	23.9	23.5	Clay (light)
5	Lamu	872	579	188	25.3	25.9	25.0	30.2	30.8	29.8	27.8	28.3	27.4	Clay loam
6	Lodwar	200	106	68	23.7	24.0	23.7	35.9	36.4	35.7	29.8	30.2	29.7	Sandy loam
7	Makindu	637	222	369	18.3	18.9	18.1	30.2	30.8	30.0	24.2	24.9	24.0	Sandy clay loam
8	Mandera	257	139	109	23.7	24.4	23.2	35.8	36.6	35.2	29.7	30.5	29.2	Sand
9	Marsabit	614	280	285	18.5	19.1	18.3	30.3	30.9	30.0	24.4	25.0	24.1	Clay (light)
10	Narok	751	412	228	10.6	11.4	10.1	24.8	25.0	24.9	17.7	18.2	17.5	Silt loam
11	Voi	620	237	332	20.9	21.5	20.6	31.5	32.1	31.3	26.2	26.8	25.9	Sandy clay loam
12	Wajir	312	164	128	23.0	23.7	22.5	34.9	35.7	34.2	28.9	29.7	28.4	Sand

Table 3. 3 Basic Descriptions for the locations: Tanzania

No.	Name of locations	Average rainfall (mm)			Average Tmin (^{O}C)			Average Tmax (^{O}C)			Average Tmean (^{O}C)			Soil texture
		Annual (mm)	FMAMJ (mm)	ASOND (mm)	Annual Tmin (^{O}C)	Tmin - FMAMJ (^{O}C)	Tmin - ASOND (^{O}C)	Av. Annual Tmax	Av. Seasonal Tmax:	Av. Seasonal Tmax:	Av. Annual Tmean (^{O}C)	Av. Seasonal Tmean:	Av. Seasonal Tmean:	
1	Arusha	1058	683	271	7.7	8.3	7.5	20.3	20.1	20.9	14.0	14.2	14.2	Loam
2	Bukoba	2082	1088	777	18.3	18.5	18.2	26.2	26.3	26.1	22.2	22.4	22.2	Sandy clay
3	Dar es Salaam	1112	636	385	21.7	22.2	21.1	31.4	30.9	32.0	26.5	26.6	26.6	Loamy sand
4	Dodoma	603	290	173	17.0	17.4	17.0	29.8	29.3	30.8	23.4	23.3	23.9	Loam
5	Kigoma	1049	471	426	19.5	19.6	19.8	28.4	28.1	28.9	24.0	23.9	24.4	Loam
6	Mbeya	1062	519	296	14.0	14.4	14.1	25.9	25.1	27.4	20.0	19.7	20.7	Clay (light)
7	Mtwara	1049	603	226	21.0	21.1	21.0	31.2	30.3	32.7	26.1	25.7	26.9	Sandy clay loam
8	Musoma	992	515	366	16.6	16.7	16.7	29.2	28.8	29.8	22.9	22.7	23.2	Sandy loam
9	Mwanza	1011	444	440	18.8	18.8	19.2	27.7	27.7	28.0	23.3	23.2	23.6	Sandy clay loam
10	Same	554	319	175	18.5	19.0	18.2	30.5	30.5	30.8	24.5	24.8	24.5	Clay (heavy)
11	Songea	1088	571	242	16.8	17.1	16.8	27.7	26.8	29.3	22.3	22.0	23.1	Sandy clay loam
12	Tabora	976	455	338	17.5	17.2	18.3	30.1	29.2	31.4	23.8	23.2	24.8	Sandy clay loam

3.2.2.2 Selection of projected future climate scenario and preparation of projected future climate data

Future climate conditions for 38 locations in East Africa were used from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (Taylor, Stouffer, & Meehl, 2009) for the early century period 2016 -2045, mid-century period 2036 - 2065 and late century period 2056 - 2085 which this research termed as the 2030s, 2050s, and 2070s for early – century period, mid-century period, and late century period respectively. The baseline period which is also the current climate was taken as 1980-2009.

Future climate data was selected for two representative concentration pathways (RCP 4.5 and 8.5) from 4 GCM models which were assessed under the Coordinated Regional Climate Downscaling Experiment (CORDEX) for the African region (Giorgi, Jones, & Asrar, 2009; C. Jones, 2013). The model selection for this study was based on the model evaluation by Giorgi et al (2009), Jones (2013) and (Vincent O. Otieno & Richard O. Anyah, 2013; Vincent O. Otieno & R. O. Anyah, 2013). Table 3.1 describes the four models therefore selected for this study. These were: 1. CSIRO-Mk3.6 (Rotstayn et al., 2009) with a horizontal resolution of 1.875 x 1.875 which uses a Rotstayn convective scheme (Rotstayn, 1998; Rotstayn et al., 2012); 2. MIROC5 (Watanabe et al., 2011) having a horizontal resolution of 1.4 x 1.4 and uses an Arakawa and Shubert convective scheme (Arakawa & Shubert, 1974); 3. MRI-CGCM3 (Yukimoto S et al, 2006) with a horizontal resolution of 1.125 x 1.12148 using a prognostic Arakawa-Shubert convective scheme (Pan & Randall, 1998); and, 4. NorESM1-M (Bentsen et al., 2012; Seland, Iversen, Kirkevag, & Storelvmo, 2008) with a horizontal resolution of 2.5 x 1.895 and uses a Zhang and McFarlane convective scheme (G. J. Zhang & McFarlane, 1995).

Table 3. 4 Description of global circulation models used

Name of model	Horizontal resolution	Model expanded name	Model group (or center)	Reference
CSIRO-Mk3.6	1.875 x 1.875	Commonwealth Scientific and Industrial Research Organization Mark, version 3.6.0	Commonwealth Scientific and Industrial Research Organization (CSIRO)/Queensland Climate Change Centre of Excellence (QCCCE)	Rotstayn et al., 2009
MIROC5	1.4 x 1.4	Model for Interdisciplinary Research on Climate, version 5	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)	Watanabe et al., 2011
MRI-CGCM3	1.125 x 1.12148	Meteorological Research Institute Coupled Atmosphere–Ocean General Circulation Model, version 3	Meteorological Research Institute (MRI)	Yukimoto S et al, 2006
NorESM1-M	2.5 x 1.895	Norwegian Earth System Model, version 1 (mid resolution)	Norwegian Climate Centre (NCC)	Bentsen et al., 2012; Seland, Iversen, Kirkevag, & Storelvmo, 2008

Biases do exist in all the convective schemes employed in GCMS and these errors of limit their utility for climate prediction and projection. In a study on tropical climates based on an intermodel empirical orthogonal function (EOF) analysis of tropical Pacific precipitation, Li and Xie (2014) found out that the excessive equatorial Pacific cold tongue and double intertropical convergence zone (ITCZ) stood out as the most prominent errors of the current generation of CGCMs. And that the equatorial Pacific cold tongue bias was associated with deficient precipitation and surface easterly wind biases in the western half of the basin in CGCMs, but the errors were absent in atmosphere-only models, indicating that the errors arose from the interaction with the ocean via Bjerknes feedback. And for the double ITCZ problem, excessive precipitation south of the equator correlated well with excessive downward solar radiation in the Southern Hemisphere (SH) midlatitudes, an error traced back to atmospheric model simulations of cloud during austral spring and summer.

Site-specific future temperature and rainfall data were stochastically downscaled for the four GCMs (CSIRO-Mk3.6, MIROC5, MRI-CGCM3, NorESM1-M) for representative concentration pathways 4.5 and 8.5 emission scenarios using MarkSim (Peter G. Jones & Thornton, 2013). MarkSim is a spatially explicit daily weather generator that uses a third-order Markov chain process to generate daily rainfall, radiation, and temperature (P.G. Jones & Thornton, 2000). It requires geographical coordinate and altitude to downscale and generates daily future data of a given site (Peter G. Jones & Thornton, 2013).

Stochastic weather generation has an advantage of mapping large-scale deterministic predictors for precipitation at small scales (Maraun et al. 2010; Chiew et al. 2010) to produce realizations of the expected small-scale rainfall field. Stochastic rainfall downscaling (Ferraris et al. 2003) aims at generating synthetic spatiotemporal precipitation fields whose statistical properties are consistent with the small-scale statistics of observed precipitation, based only on knowledge of the large-scale precipitation field. Stochastic downscaling also has the potential for estimating uncertainties in rainfall scenarios, by generating large ensembles of synthetic small-scale precipitation fields that can be compared with measured data (Brussolo et al. 2008). The major disadvantage is that stochastic downscaling is not a substitute for physically based models, because it relies on statistical models and algorithms to generate climate does not use physical process.

In the weather generator, monthly climate anomalies (absolute changes) for monthly rainfall, mean daily maximum temperature and mean daily minimum temperature was calculated for each time slice relative to the baseline climatology (1961–1990). The point of origin was designated 1975, being the midpoint of the 30-year climate normal (Jones & Thornton, 2013). In this study, future temperature and rainfall changes were downloaded from the website, (http://gismap.ciat.cgiar.org/MarkSimGCM/) for 4 time slots 2010-2020 (2010s) as the control period, the early century period 2030-2040 (2030s), mid-century period 2050-2060 (2050s) and late century period 2070-2080 (2070s) which are centered around 2015, 2035, 2055 and 2075 respectively. We used the WorldClim dataset (Peter G. Jones & Thornton, 2013) as the base period and 2015 (2010-2020) as the control period. Differences between averages in temperature and percentage change in precipitation were used to describe future climatic changes in relation to the control period.

This study, therefore, used three different groups of climate data. The historical observed data for the period 1980 – 2009, the stochastically generated current climate data for 30 years, and stochastically projected future climate data. The stochastically projected future climate data for the two representative concentration pathways, RCP4.5 and RCP8.5 was for the early century period 2016 -2045, mid-century period 2036 - 2065 and late century period 2056 -2085 which this research referred to as the 2030s, 2050s, and 2070s for early – century period, mid-century period, and late century period respectively. The historical observed data was used to examine climate trends for the historical period; the stochastically generated current climate was compared with historical observed climate to test on the similarities between these two datasets especially on capturing seasonal variations, and the stochastical generated future climate data was used to generate the relative changes in climate. Then all these datasets were run in SPOTCOMS and a climate change impact assessment on sweet potato production was performed.

3.2.2.3 Wet or dry GCM models and hot or cool GCM models

The spatial distribution of precipitation between the historical long-term mean WorldClim dataset and the current period of 1980 - 2009 for the four GCMS showed small contrast. All the GCMs showed a consistent pattern in the distribution of precipitation with the Eastern parts of East Africa encompassing most areas in Kenya and high-elevation areas of Arusha through central Tanzania showing the least amount of annual precipitation below 500 mm (Figure 3.3). The GCMs showed slight variation and almost hard to make a distinction between RCP4.5 and RCP8.5.

The temperatures from current control period of 2015 are also quite similar in the spatial distribution and variation (Figure 3.4). For all the models, the Eastern strip of East Africa and northern parts are the warmest with an average temperature in the range of 28-30 ^{0}C. Generally, all GCMs showed similarly high temperatures.

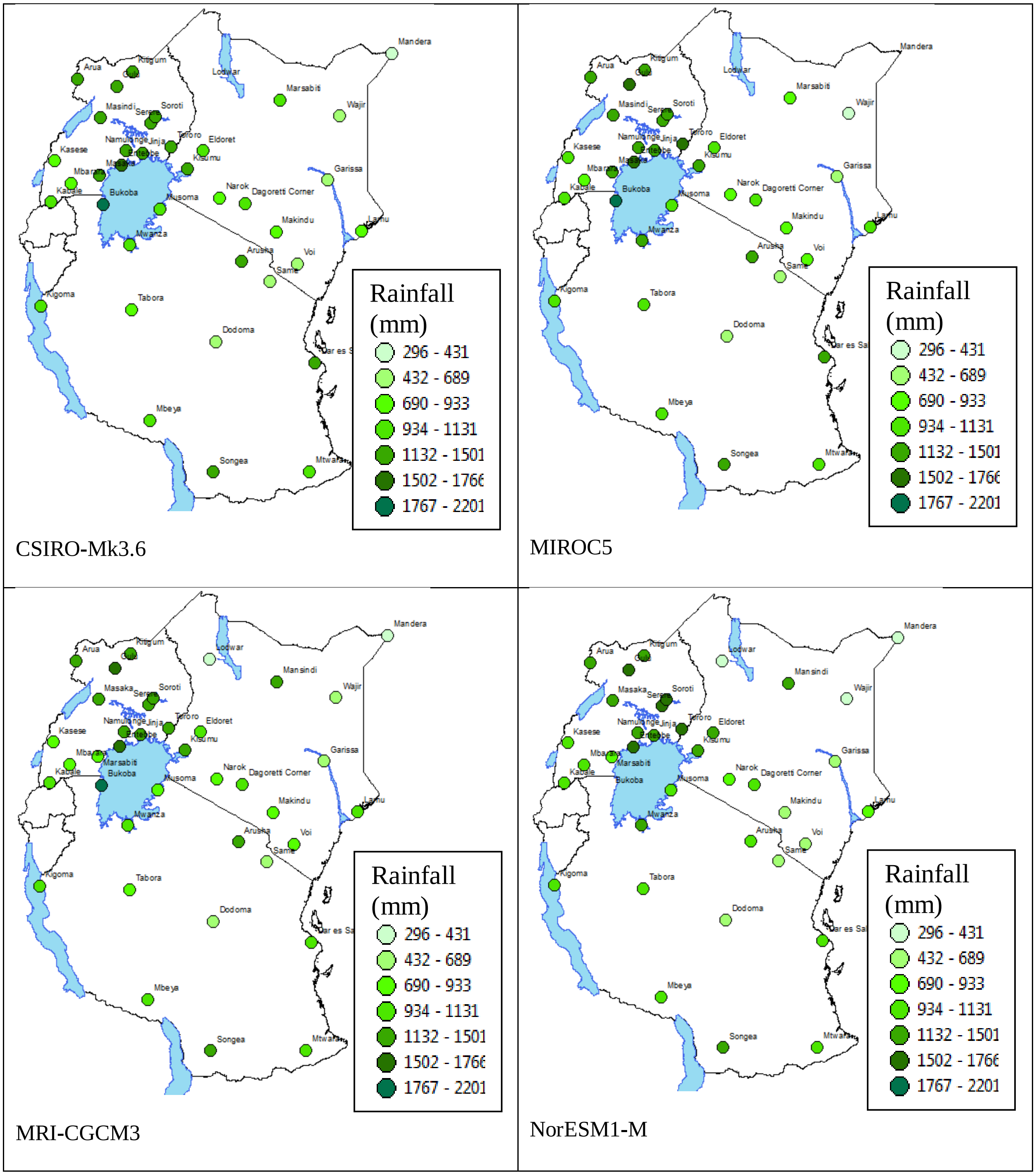


Figure 3. 3 Spatial distribution of stochastically generated current mean annual rainfall over East Africa for the period1980 - 2009

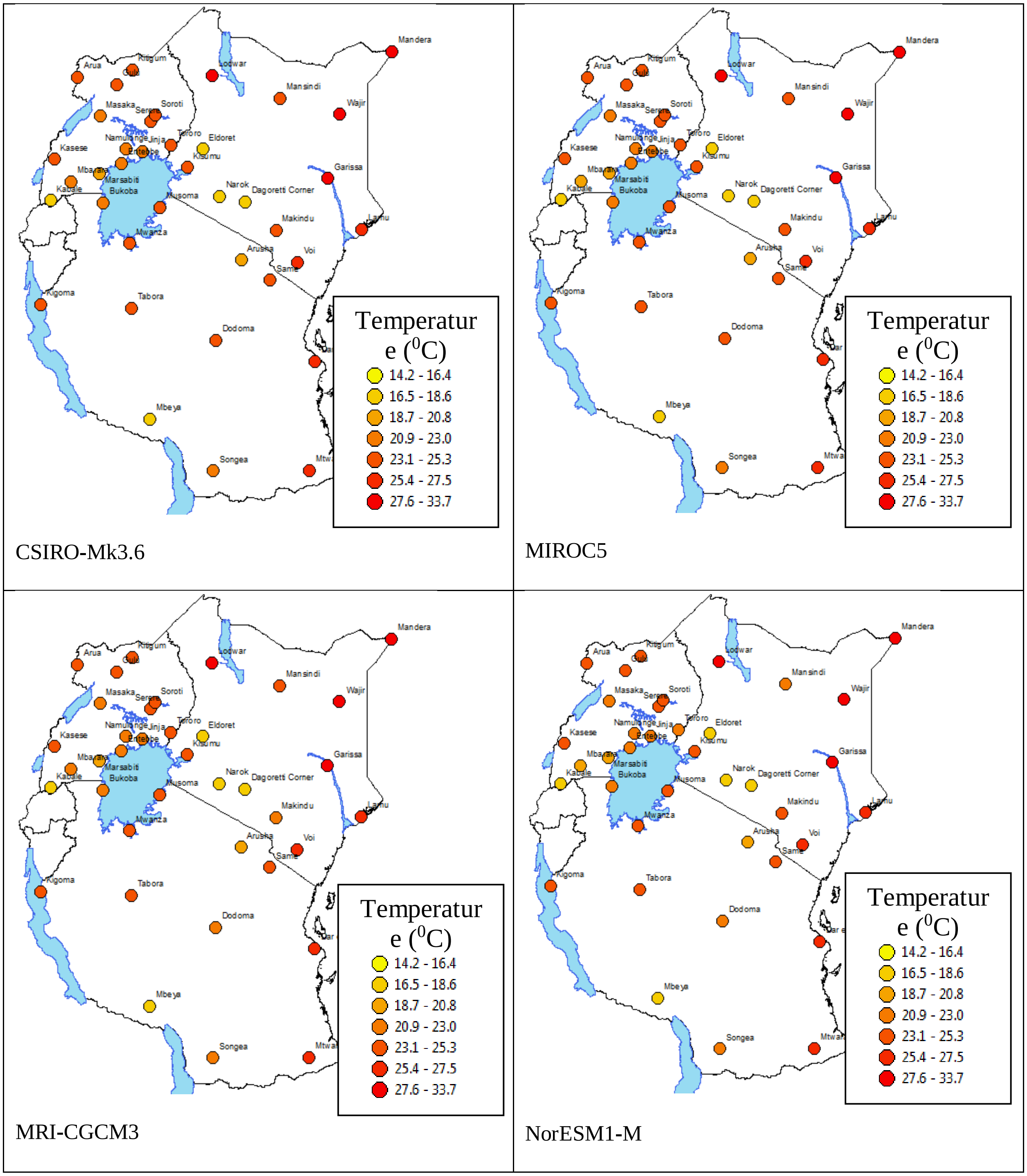


Figure 3. 4 Spatial distribution of stochastically generated current mean annual temperature over East Africa

3.2.3 Trend analysis

Trend magnitudes of historical climate and derived simulated sweet potato yields and their significance were calculated across East Africa using a non-parametric statistic that follows a methodology by (Sen, 1968) was used. This nonparametric method is less sensitivity to outliers and tests for a trend in a time series without specifying whether the trend is linear or nonlinear (Partal & Kahya, 2006; Yenigun, Gumus, & H., 2008). And it is a good choice for analyzing trends from variables that are not normally distributed especially precipitation. This study follows the same steps as those used in (Andresen, Alagarswamy, Rotz, Ritchie, & LeBaron, 2001). Briefly, the trend magnitude statistic (B) is defined as

$$B = med\{D_{ij}\} \qquad [15]$$

Were $D_{ij} = (x_j - x_i)/(j - i)$ for all possible pairs (x_i, x_j), $1 \leq i < j \leq n$, and n the number of observations in the series. For the case of this study, n = 30. The nonparametric Mann-Kendall or Kendall's tau statistic (Kendall, 1975) was used to determine the significance of the trends. The null hypothesis, H_0, was that the data in the series of interest $(x_1, x_2, \dots x_n)$ were a sample of n independent and identically distributed variables. The alternative hypothesis, H_1, of the two-sided test was that the distribution of x_i and x_j were not identical for all pairs of $i, j \leq n$, and $i \neq j$. The series were analyzed with a two-sided test for trend, with H_0 accepted if the standard normal variate of S was less than or equal to the standard normal cumulative distribution function for a given level of significance $\propto$, $|Z| \leq z_{\propto/2}$. The power of this test for sample sizes > 10 has been shown to be nearly as great as that of the more traditional t-statistic, which assumes normality (Hirsch, Slack, & Smith, 1982; Kendall, 1975).

Twelve variables were used in the trend analysis including seasonal precipitation and mean temperature both the long rains season February – June (FMAMJ) and the short rains season August – December (ASOND) and the seasonal yields for the four sweet potato cultivars NASPOT1 (na1), NASPOT 10 0 (na10), NASPOT 11 (na11) and SPK004 – Kakamega (spk). The variables are abbreviated as PPT- FMAMJ, PPT-ASOND, Tmean- FMAMJ, Tmean- ASOND, na1-ASOND, na1-ASOND, na10-ASOND, spk004-ASOND, na1-FMAMJ, na10-FMAMJ, na11-FMAMJ, spk004-FMAMJ

3.2.4 Sensitivity analysis

Sensitivity analysis of SPOTCOMS model was performed for changes in temperature and precipitation using observed historical climate and soils data. The aim was to analyze the effect of changes in climatic variability on sweet potato growth and development, as simulated by SPOTCOMS. The analysis was made for the four sweet potato cultivars, NASPOT 1, NASPOT 10 0, NASPOT 11 and Kakamega (SPK 004) following a methodology used by Katz and Brown (1992), Mearns et al. (1992), Semenov and Porter (1995. Various research groups (Katz and Brown, 1992; Mearns et al., 1992; Semenov and Porter, 1995) have conducted studies on the effects of climatic change on crop growth and development. Katz and Brown (1992) found that extreme climatological events are relatively more dependent on changes in climatic variability than on changes in mean values, especially for hot spells and droughts. Mearns et al. (1992) and Semenov and Porter (1995) investigated how changes in climatic variability could affect wheat production and performed sensitivity analyses using the CERES-Wheat crop simulation model and historical climatic data perturbed to increase the inter-annual variance of the climatic variables. Semenov and Porter (1995)

A sensitivity analysis was performed to identify the major climatic constraints for sweet potato development and yield. The analysis was carried out for Namulonge in Uganda, Mbeya in Tanzania and Dagoretti Corner in Kenya. These locations were selected as representative sites for climate across East Africa. The choice for selection of these locations was based on the premise that the three locations representative average climatic patterns from their respective countries. The daily rainfall totals of each of these locations was changed in the range of -/+ 50% at increments of -/+10% and the daily minimum and maximum temperatures were also changed by -/+ 1^0C increments in the range -/+ 5^0C following a methodology by Katz and Brown (1992), Mearns et al. (1992) and Semenov and Porter (1995). This, therefore, led to 121 different combinations of model runs for a particular location. For temperatures, the maximum and minimum temperatures were either decreased or increased together. For example, when the maximum temperature was increased by 2^0C, the same change was performed on the minimum temperatures. To perform an evaluation of the sensitivity analysis, graphs were plotted using Microsoft Excel and surface diagrams were plotted using Sigma Plot.

3.2.5 Climate change impact assessment

In order to investigate the impact of future climate change, the SPOTCOMS was used to stimulate growth, development, and yield of sweet potato across East Africa. SPOTOMS is a process-based crop model that stimulates growth, development, and yield of sweet potatoes (Mithra & Somasundaram, 2008). The SPOTCOMS and the experimentation that was used to calibrate it for the East African region was described in chapter two. For all the locations used in this study, the planting date as defined for model simulation was taken to be the beginning of the growing season which was February 1st for the February to May season and August 1st for the

August to December growing season. The planting date is very important because when it is changed, the model simulates different results as it will be taking different climate data corresponding to the modified growing season. The model was used to simulate the phenology and yield of sweet potato, in response to climatic factors, namely precipitation, maximum and minimum temperatures and solar radiation. SPOTCOMS employs soil data, crop management data, and daily meteorological data as an input to simulate daily leaf area index (LAI) and vegetation status parameters, biomass production, and final yield. The daily meteorological data include solar radiation, rainfall, and maximum and minimum air temperatures. The major soil data include soil type, initial soil water content, relative root distribution, soil pH, bulk density, and soil organic matter. The crop management data include variety, planting date, plant density, irrigation, and fertilizer application. Crop genetic coefficients included in the model relates to the photoperiod sensitivity (thermal time), growth stages of sweet potatoes, development of vines, describes the development of roots, branching of the crop, the number of leaves on a sweet potato plant and the leaf area of sweet potatoes.

An assessment of climate change impact on the yield for four representative cultivars of sweet potatoes NASPOT 1, NASPOT 10 0, NASPOT 11, and SPK004 (Kakamega) was performed. The model was calibrated and validated for these cultivars using experimental data collected at Namulonge Crops Resources Research Institute (NaCRRI) in Uganda, details of the whole process were presented in chapter two.

In this impact assessment, SPOTCOMS was run using three different types of climate data. One dataset was historical observed data for the period 1980 – 2009, the second dataset was the stochastically generated current climate data for 30 years, and third, stochastically projected future climate data. The stochastically projected future climate data for the two representative concentration pathways, RCP4.5 and RCP8.5 was for the early century period 2016 -2045, mid-century period 2036 - 2065 and late century period 2056 -2085 which this research referred to as the 2030s, 2050s, and 2070s for early – century period, mid-century period, and late century period respectively.

3.3 Results

3.3.1 Trend analysis

The results from the seasonal trend analysis of precipitation, Figure 3.5 and Figure 3.6, indicated that the long-rainfall-season (February-June) intensity decreased northwards with highest increases of more than 3.5 mm/yr in southern parts of Tanzania and decreases of more than 3.9 mm/yr in northern parts of Kenya and Uganda. The trail of decreasing precipitation largely falls along the eastern arm of the East African rift valley from northern Kenya into Tanzania. The average temperatures trend of the same season, on the other hand, increased from the south-west direction towards the north-west direction in East Africa (Figures 3.7 and Figure 3.8). The magnitudes of this increase varied from 0^0C on the Indian Ocean to more than 1.5^0C over the 30 year period in most parts of Uganda and north-west parts of Tanzania and Kenya. Sweet potato yields in the February-June season, for the three cultivars, NASPOT 1, NASPOT 10 O and NASPOT 11 (Table 3.5) increased with magnitudes of 0.6-3 t/ha (or 0.02 - 0.11 t/ha/yr) in most parts of Uganda and Tanzania with the exception of the north-eastern parts of Tanzania. And, the yields decreased in most parts of Kenya especially the areas along the eastern arm of the rift-valley by magnitudes of more than 0.11 t/ha/yr or 3.3 t/ha. The SPK004 sweet potato cultivar showed a slightly different trend (Table 3.5). The increase in SPK004 yields largely followed an East to

West pattern across East Africa. And the decrease in SPK004 yields was not as large as the one shown by the other cultivars.

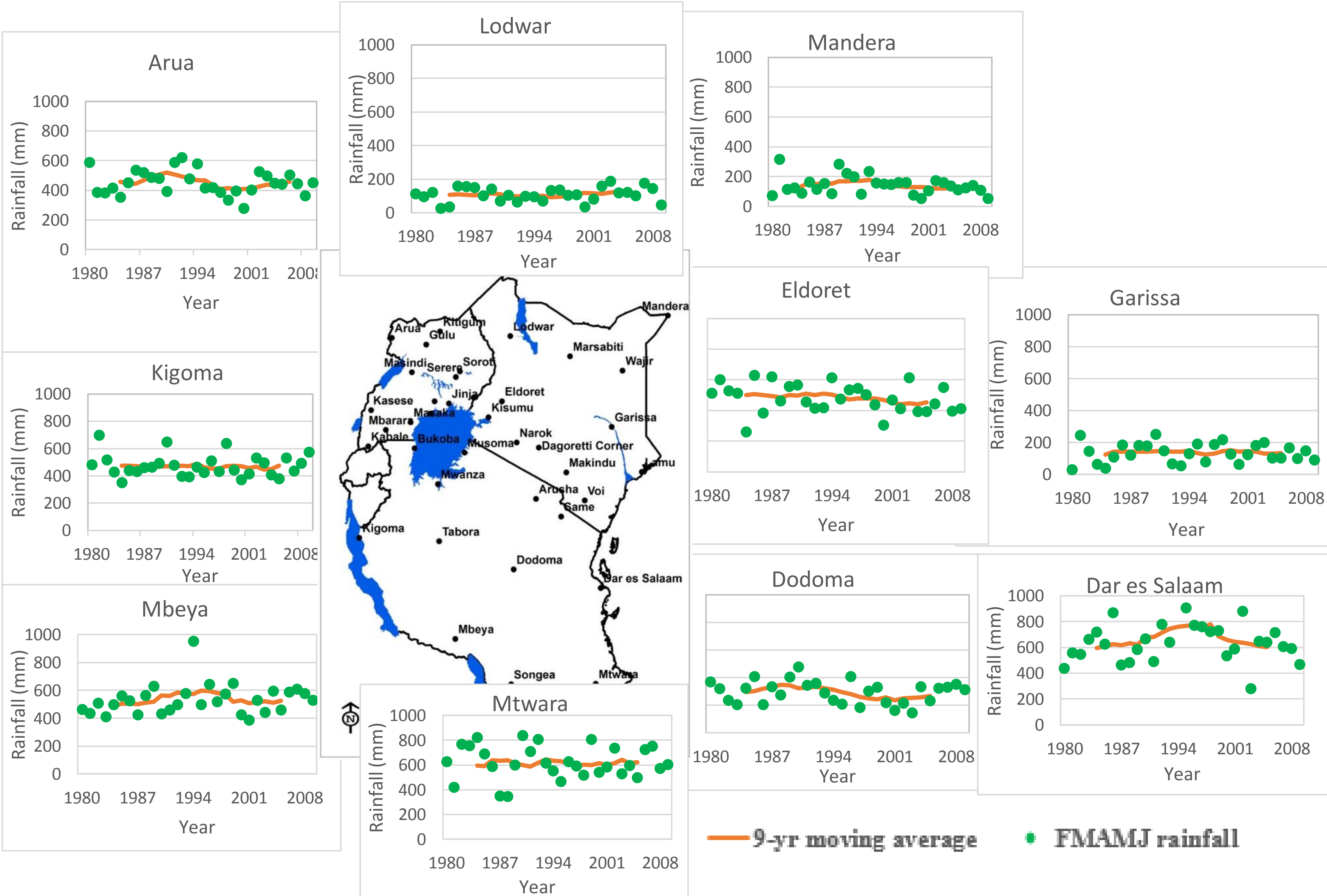


Figure 3. 5 Trend in average rainfall over the February to June (FMAMJ) season for selected locations over the period 1980 - 2009 across East Africa

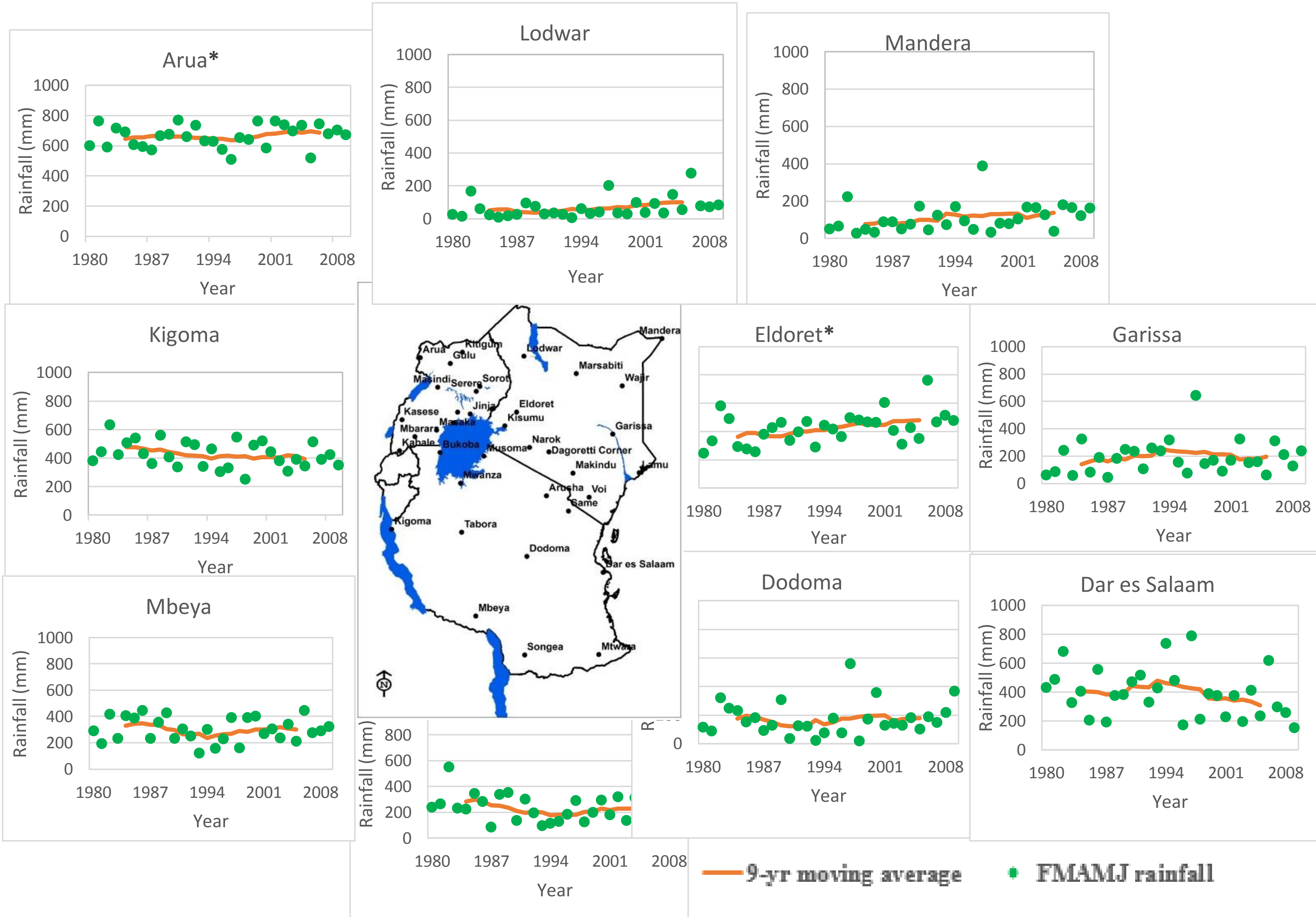


Figure 3. 6 Trend in average rainfall over the August to December (ASOND) season for selected locations over the period 1980 - 2009 across East Africa. The * represent a significant trend at 0.05 level

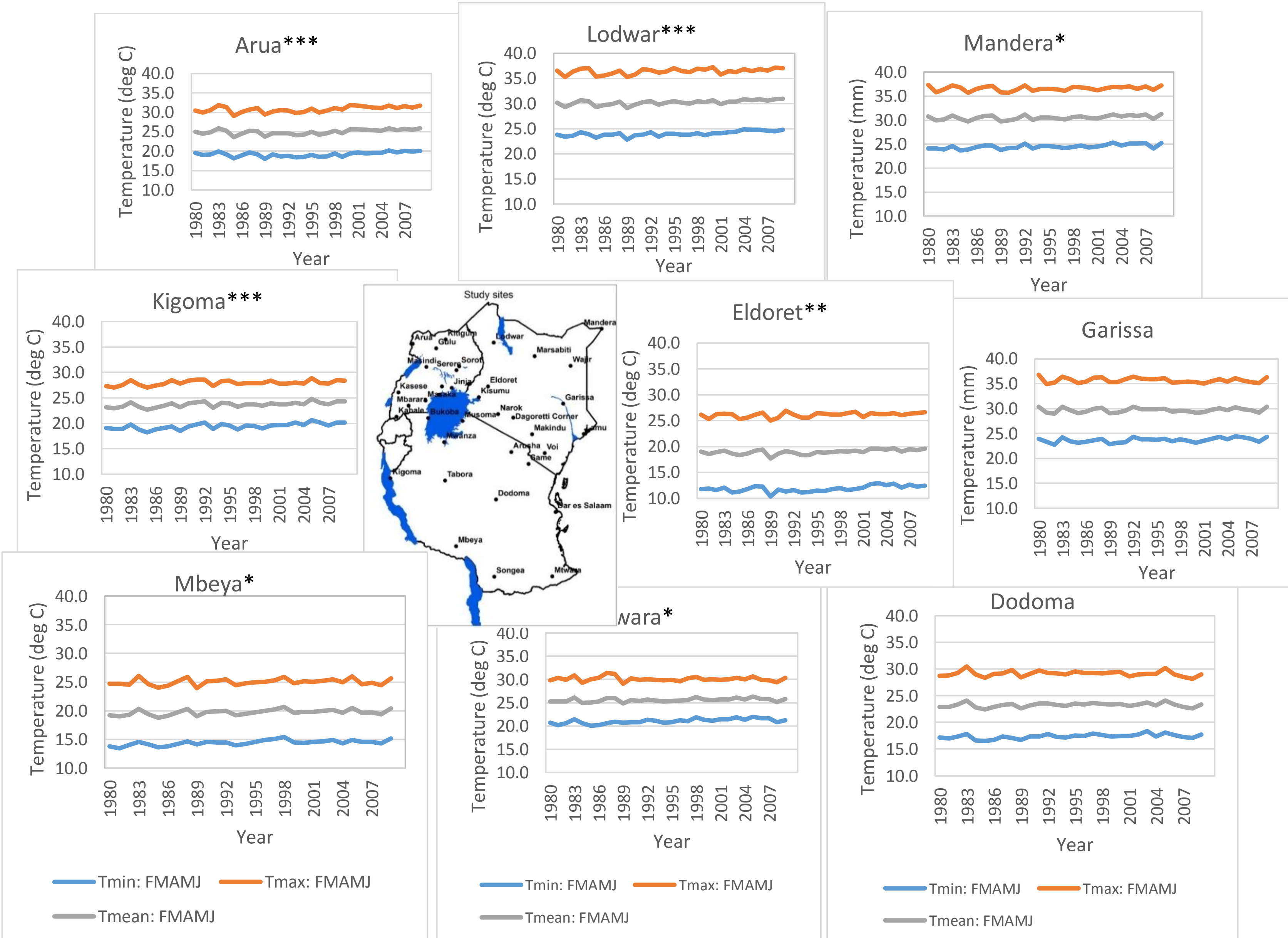


Figure 3. 7 Trend in average temperature over the February to June (FMAMJ) season for selected locations over the period 1980 - 2009 across East Africa. *, **. And *** represent a significant trend at 0.05, 0.01, 0.001 levels respectively.

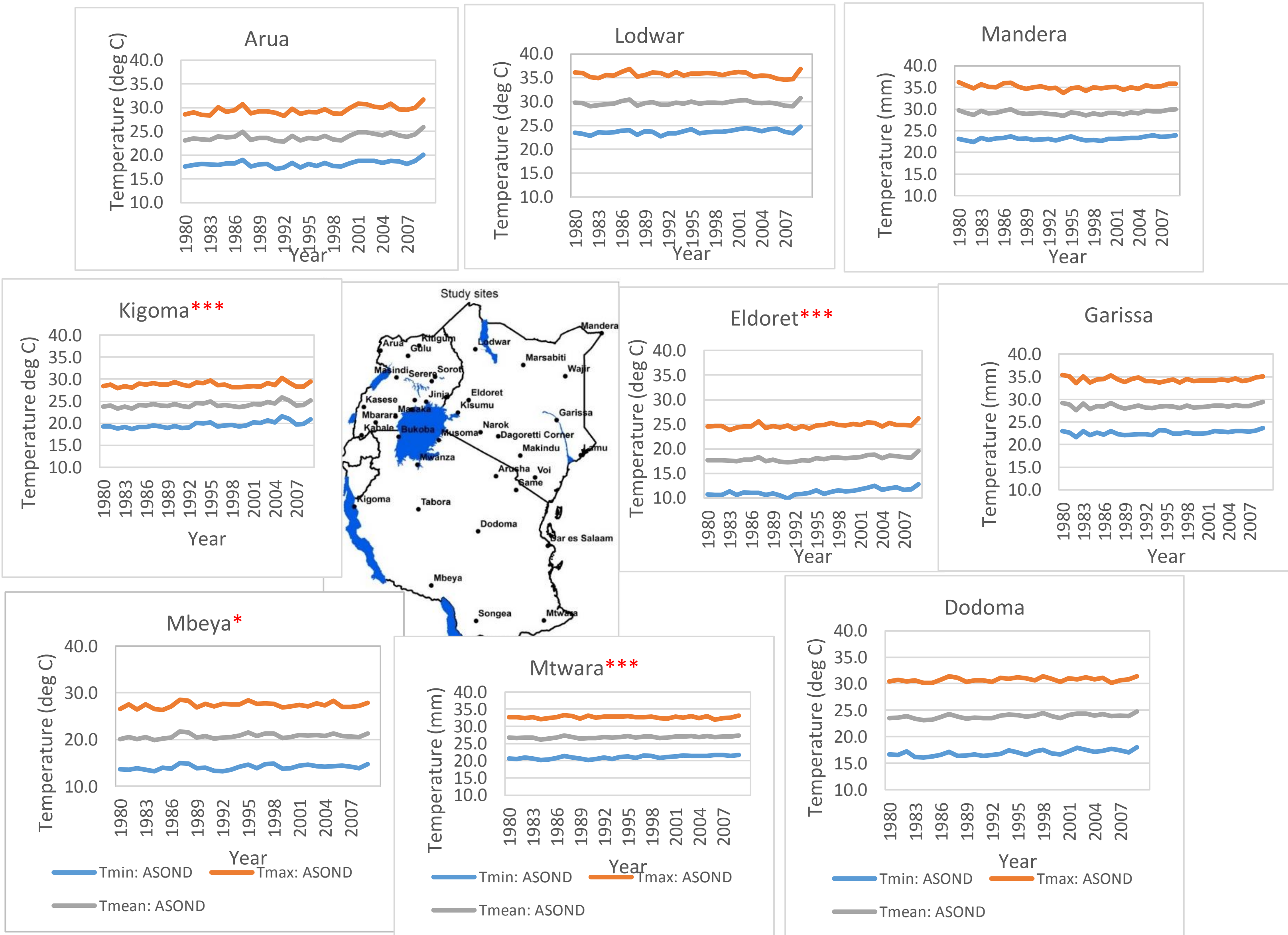


Figure 3. 8 Trend in average temperature over the August to December (ASOND) season for selected locations over the period 1980 - 2009 across East Africa. *, **. And *** represent a significant trend at 0.05, 0.01, 0.001 levels respectively.

The results from the seasonal trend analysis of precipitation, Figure 3.8, indicated that the short -rainfall-season (August-December) intensity increased northwards with highest increases of more than 1mm/yr across most parts of Uganda, Kenya and areas surrounding Lake Victoria. There were decreases in precipitation of more than 2.34 mm/yr (> 60mm) in areas along the Indian Coast (Figure 3.8). The average temperatures trend of the August-December season showed increases of 1.2^0C in most parts of East Africa with the exception of a few areas along the Indian Ocean and Eastern Kenya. Sweet potato yield trends in the August-December season for the four cultivars, NASPOT, NASPOT 10 O (Figure 3.3d) and NASPOT 11 and SPK004 Table 3.5 increased from the south to north with magnitudes of 0.04 t/ha/yr to 0.5 t/ha/yr (1.2 - 15 t/ha).

Results from significance tests in the trends of variables indicated that the mean temperature for both seasons was largely significant at 0.001 level of significance (S.L) for most areas across East Africa (Figure 3.8). Precipitation for the August-December season (PPT-ASOND) recorded some significance at locations, Gulu (0.01 S.L) and Eldoret (0.05 S.L). The variables for yields for the four cultivars across both seasons did not show significant trends accept at a few scattered locations.

Table 3. 5 Trend statistics for agroclimatological variables† for the period 1980 - 2009 by site and season.

No	Location	Country	Precipitation (mm/yr)		Mean Temperature (^0C/yr)		Simulated sweet potato yield (kg/ha/yr)							
							Short rainfall season (ASOND)				Long rainfall season (FMAMJ)			
			FMAMJ	ASOND	FMAMJ	ASOND	na1	na10	na11	spk004	na1	na10	na11	spk004
1	Arua		-1.067	1.350**	0.037***	0.043	0.015	-0.039	0.004	-0.053	0.267**	0.275**	0.494**	0.158*
2	Entebbe		-0.587	0.436	0.045***	0.038***	0.258	0.200	0.290	0.172	0.093	0.059	-0.035	0.049
3	Gulu		-3.256	5.608*	0.041**	0.026*	0.199	0.089*	0.672*	0.138**	0.089	0.058	-0.056	0.064
4	Jinja		0.320	1.018	0.052***	0.050***	0.360*	0.360*	0.298	0.254*	0.355**	0.037	0.059	0.061
5	Kabale	U	-0.211	-1.052	0.041***	0.040***	0.153	0.158	0.133	0.160	0.177*	0.184*	0.158*	0.160
6	Kasese	G	-0.613	1.083	0.046***	0.028	0.328	0.111	0.374	0.075	0.138	0.111	0.110	0.063
7	Kitgum	A	-1.650	2.843	0.032**	0.018	0.216	0.310	0.253	0.160*	0.066	0.030	0.110	-0.020
8	Masaka	N	-5.117	-4.186	0.054***	0.048***	-0.003	0.010	0.014	-0.040	-0.013	-0.039	-0.250	0.004
9	Masindi	D	-2.700	1.452	0.056***	0.044***	0.247	0.180	0.297	0.085	0.124	0.110	0.111	0.104
10	Mbarara	A	1.800	1.282	0.044***	0.040***	0.240	0.183	0.267	0.111	0.219*	0.239*	0.184*	0.227*
11	Namulonge		0.183	3.360	0.047***	0.040***	0.356*	0.390**	0.449*	0.217	0.270	0.237	0.263	0.245
12	Serere		-1.620	3.382	0.039***	0.028**	0.351	0.252	0.369	0.062	0.023	-0.021	-0.076	0.044
13	Soroti		-1.091	2.408	0.046***	0.052***	0.177	0.097	0.170	0.126	0.001	0.012	-0.059	0.030
14	Tororo		0.100	5.800	0.042***	0.043***	0.351*	0.188	0.676*	0.005	0.082	0.127	0.058	0.109
15	Arusha	T	-3.569	-0.839	0.030**	0.052***	0.088	0.090	0.089	0.105	0.104	0.161	-0.008	0.150*
16	Bukoba	A	0.024	-1.727	0.044***	0.043***	0.149	0.210	0.197	0.056	0.015	0.044	0.066	0.031
17	Dar es Salaam	N Z	0.800	-6.136	-0.005	0.009	-0.067	-0.049	-0.170	-0.091	0.093	0.089	0.143	0.002
18	Dodoma	A	-1.433	1.136	0.009	0.027	0.067	0.063	0.059	0.057	-0.088	-0.047	-0.068	0.076
19	Kigoma	N	0.063	-3.086	0.034***	0.031***	0.021	-0.014	-0.069	-0.008	0.042	0.044	0.202	0.064
20	Mbeya	I	2.390	-0.408	0.027*	0.021*	-0.019	-0.030	-0.003	-0.001	0.203	0.026	0.383	0.078
21	Mtwara	A	-1.586	-2.662	0.020*	0.020***	-0.067	-0.043	-0.073	-0.023	0.001	-0.005	0.094	-0.036
22	Musoma		-7.080	3.950	0.029***	0.019	0.322	0.283	0.266	0.274	-0.340	-0.189	-0.603*	-0.032

Table 3.5 (Cont'd)

No	Location	Country	Precipitation (mm/yr)		Mean Temperature (^{0}C/yr)		Simulated sweet potato yield (kg/ha/yr)							
							Short rainfall season (ASOND)				Long rainfall season (FMAMJ)			
			FMAMJ	ASOND	FMAMJ	ASOND	na1	na10	na11	spk004	na1	na10	na11	spk004
23	Mwanza	TANZANIA	-2.700	3.472	0.024**	0.018*	0.136	0.169	0.215	0.125	-0.015	0.006	-0.193	0.033
24	Same		-1.537	-0.506	0.010	0.030***	0.011	0.009	0.010	0.003	-0.157	-0.127	-0.135	-0.152
25	Songea		2.952	-0.209	0.021*	0.044***	-0.017	-0.019	-0.013	-0.019	0.050	0.040	0.074	0.007
26	Tabora		-0.100	0.208	0.021	0.032***	-0.022	0.004	-0.022	0.023	0.070	0.099	0.175	0.055
27	Dagoretti Corner	KENYA	-2.961	-0.280	0.019	0.040**	0.008	0.007	0.008	0.020	-0.071	0.005	-0.214	-0.023
28	Eldoret		-3.831	5.256*	0.029**	0.038***	0.224**	0.230**	0.209**	0.257*	-0.174	-0.204	-0.156	-0.209
29	Garrisa		0.186	2.170	0.007	0.013	0.087	0.064	0.065	0.071	0.004	0.002	0.002	-0.002
30	Kisumu		-1.218	5.323	0.028***	0.029***	0.287	0.292	0.299	0.185	0.067	0.083	-0.061	0.176
31	Lamu		-0.257	0.245	0.022*	0.020**	0.038	0.028	0.030	0.026	-0.040	0.028	-0.057	0.007
32	Lodwar		0.741	1.827	0.033***	0.010	0.022	0.020	0.021	0.024	0.054	0.047	0.050	0.059
33	Makindu		-0.290	-0.567	0.020	0.034***	-0.006	-0.020	0.018	0.025	-0.091	-0.071	-0.071	-0.067
34	Mandera		-1.300	3.079	0.029*	0.008	0.259	0.239	0.206	0.225	-0.175	-0.154	-0.150	-0.125
35	Marsabit		-4.925	0.947	0.030**	0.040***	0.024	-0.009	0.001	0.026	-0.073	-0.215	-0.287*	-0.133
36	Narok		-0.792	1.853	0.027***	0.038***	0.046	0.047	0.046	0.038	0.093	0.123	0.083	0.092
37	Voi		0.386	-1.160	0.006	0.019*	0.104	0.104	0.207	0.079	0.026	-0.008	0.008	0.056
38	Wajir		-0.031	2.250	0.024*	0.030*	0.192	0.168	0.161	0.160	0.017	0.017	0.030	0.032

* Significant at the 0.05 level.

** Significant at the 0.01 level.

*** Significant at the 0.001 level.

† PPT, precipitation (mm/yr); Tmean, mean temperature (^{0}C/yr); na1, NASPOT 1; na10, NASPOT 10 0; spk004, SPK004 9Kakamega); na11, NASPOT11; are yield (t/ha/yr)

FMAMJ, February – June; ASOND, August-December

3.3.2 Sensitivity analysis

The general observation from results in the sensitivity analysis shows that sweet potato root yields increase with increasing precipitation and increasing temperatures (Figures 3.9 and 3.10). The results also indicate the dry and cooler places record the lower yields than wet and cooler regions. Likewise, dry and hotter regions produce lower yields than wet and hotter regions.

On comparing the sensitivity analysis between seasons, some differences were observed in the magnitude of sweet potato yield for Dagoretti Corner, Kenya and in Mbeya, Tanzania while no big difference in variation was shown for cultivars at Namulonge, Uganda. Indeed, yields for the August-December season (Figure 3.9) for Mbeya and Dagoretti are only half those of their corresponding February-June season (Figure 3.10) in the two countries.

A comparison between location sensitivity shows that the seasonal distribution of precipitation and maximum and minimum temperatures largely determines the trends in the variation of the yield. For example, Namulonge in Uganda shows a wider variation of yields for a different combination of precipitation and temperatures compared to Dagoretti in Kenya and Mbeya in Tanzania. There were no major differences in variation of sensitivity results among different cultivars. In most of the graphs, the yield curves appeared to simply continue rising with increasing precipitation and temperature, although they seemed to begin appearing as though they were reaching the optimum threshold above which sweet potato growth is inhibited. An extensive summary of the sweet potato yields is attached to a table in the appendix.

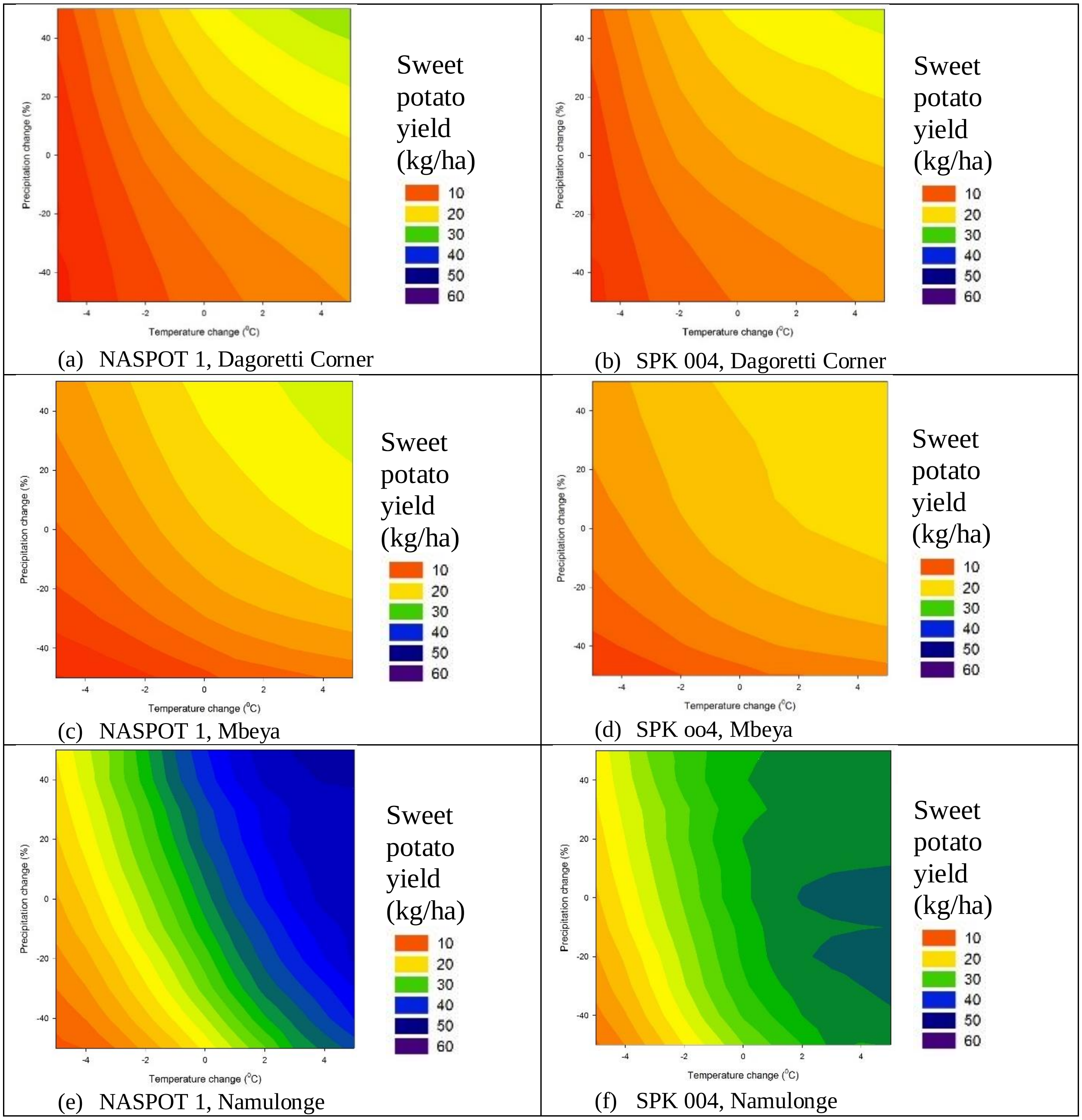


Figure 3. 9 Climate sensitivity of sweet potato crop model (SPOTCOMS) for the August to December season for 3 locations; Dagoretti Corner in Kenya, Mbeya in Tanzania and Namulonge in Uganda for two sweet potato cultivars NASPOT 1 and SPK 004. The simulated sweet potato yield was as a result of rainfall and temperatures which had been either increased or decreased by a given proportional change in rainfall and a changed amount in both minimum and maximum temperatures.

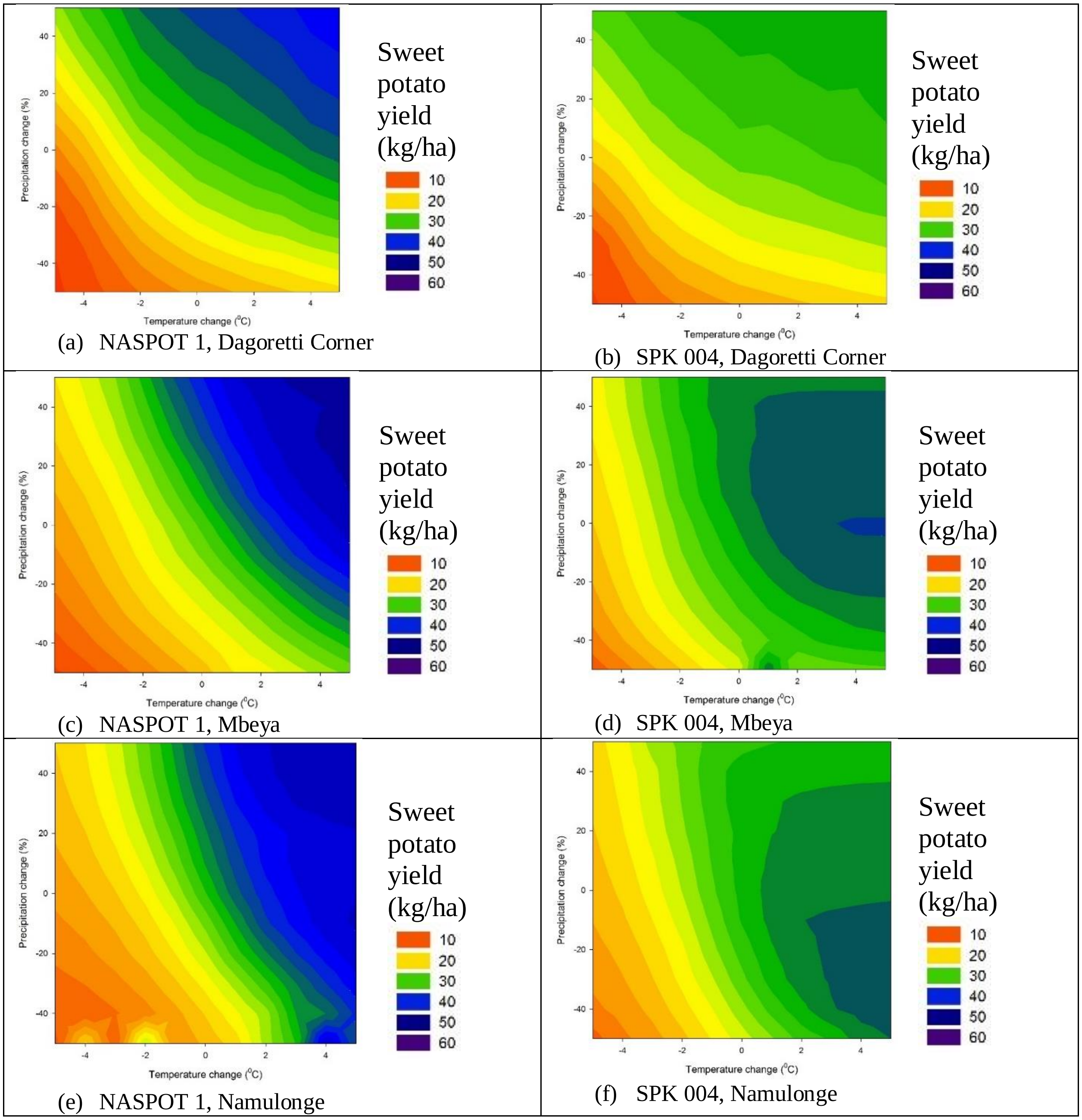


Figure 3. 10 Climate sensitivity of sweet potato crop model (SPOTCOMS) for the February to June (FMAMJ) season for 3 locations; Dagoretti Corner in Kenya, Mbeya in Tanzania and Namulonge in Uganda for two sweet potato cultivars NASPOT 1 and SPK 004. The simulated sweet potato yield was as a result of rainfall and temperatures which had been either increased or decreased by a given proportional change in rainfall and a changed amount in both minimum and maximum temperatures.

3.3.2 Projected future climate and sweet potato production model results

3.3.2.1 Future climate projections for East Africa

Most parts of Kenya and Tanzania and northern Uganda are projected to receive an increase in precipitation of more than 50 mm while western and central Uganda and southern Tanzania will experience a decrease in precipitation of more than 70 mm in the 2030s (Figures3.15 and 3.16). The drier GCM shows a decrease in precipitation in most parts of Tanzania and Uganda Southeastern parts of Kenya and parts of TZ coastline are projected to receive more rainfall of 50mm compared to the 2010s by NorESM-1. Temperatures are projected to increase in the range 0.9-1.8^{0}C in western regions of East Africa enclosing Uganda, most parts of TZ and some parts of Kenya.

In the 2070s, central parts of East Africa are projected to receive more than 90mm of annual precipitation (Figures 3.15, 3.16, 3.17 and 3.18). The southern parts of Tanzania will experience a reduction in annual precipitation of more than 75 mm as shown by both GCMs and their corresponding RCPs. For temperatures in the 2070s, the RCP4.5 scenario (Figures 3.13) shows slight increases in temperature with larger values in western regions of East Africa including Uganda and parts of Tanzania of about 1.3^{0}C. Higher temperature changes of 2.3-4^{0}C are projected for most parts of East Africa by MRICGC3-M RcP8.5 (Figure 3.14) and south-western parts of Tanzania in NorESM-1 RCP8.5 (Figure 3.14).

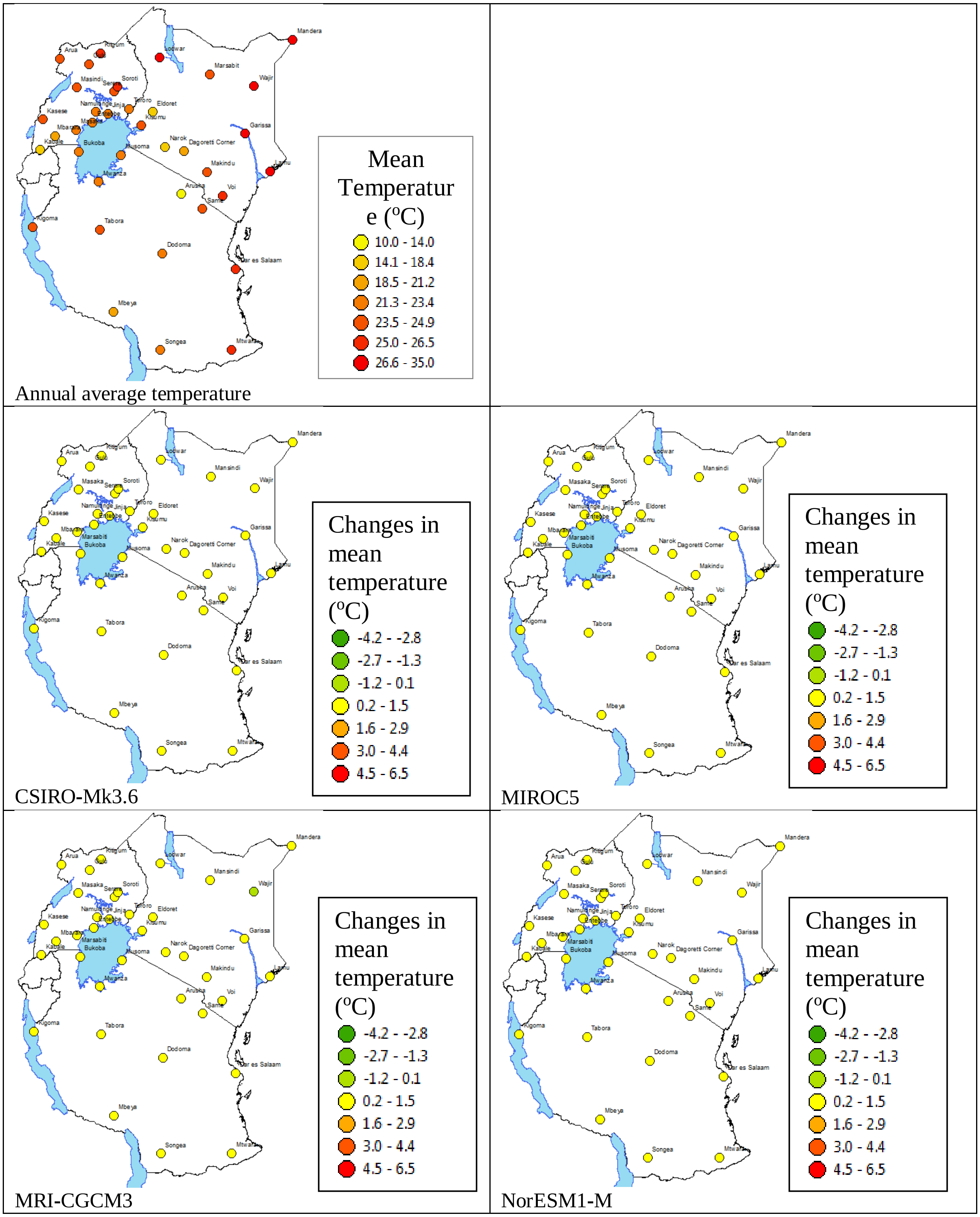


Figure 3. 11 Historical mean annual temperature and relative changes of mean annual temperatures for the 2030s for RCP4.5 for four GCMs

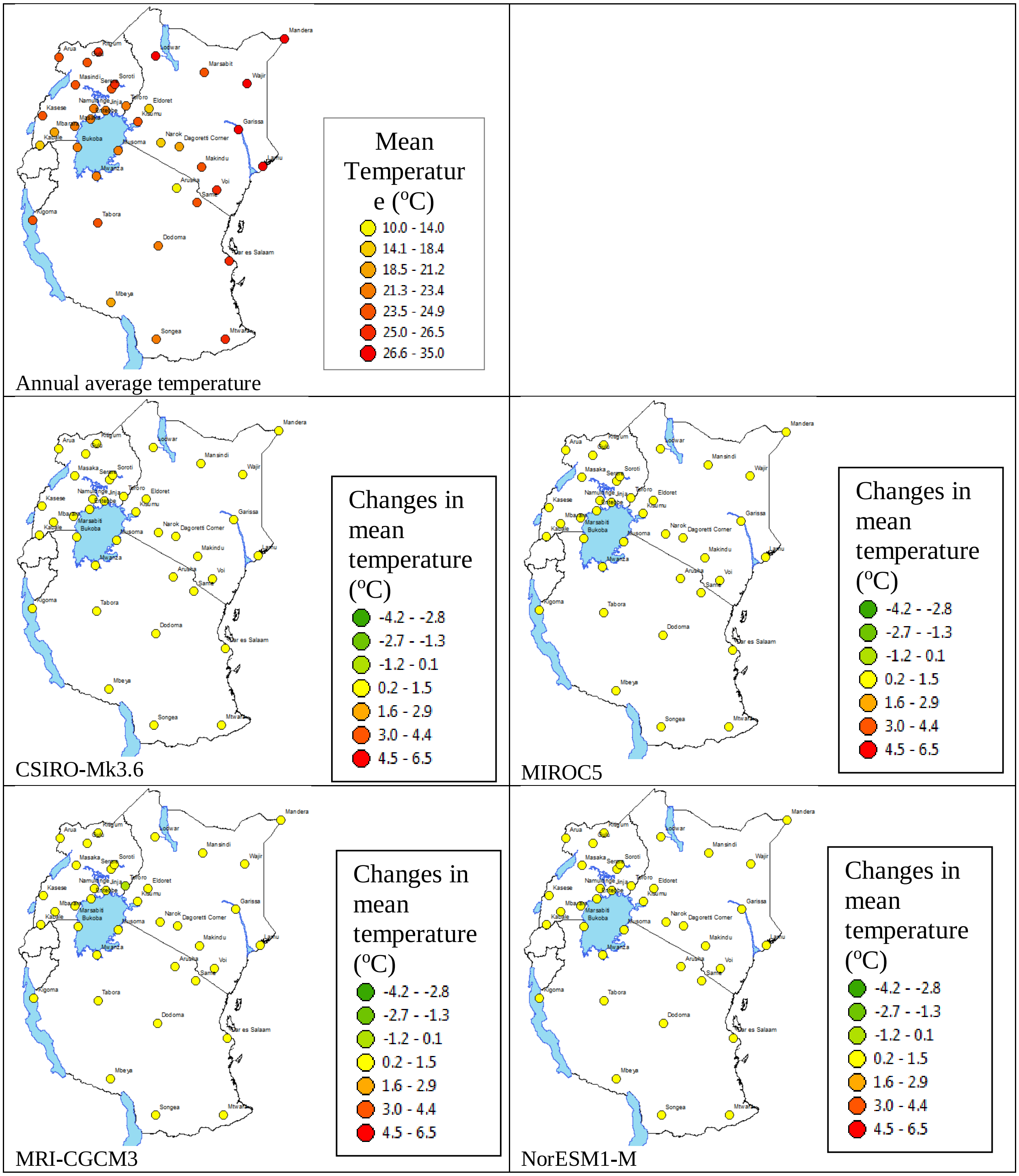


Figure 3. 12 Historical mean annual temperature and relative changes of mean annual temperatures for the 2030s for RCP8.5 for four GCMs

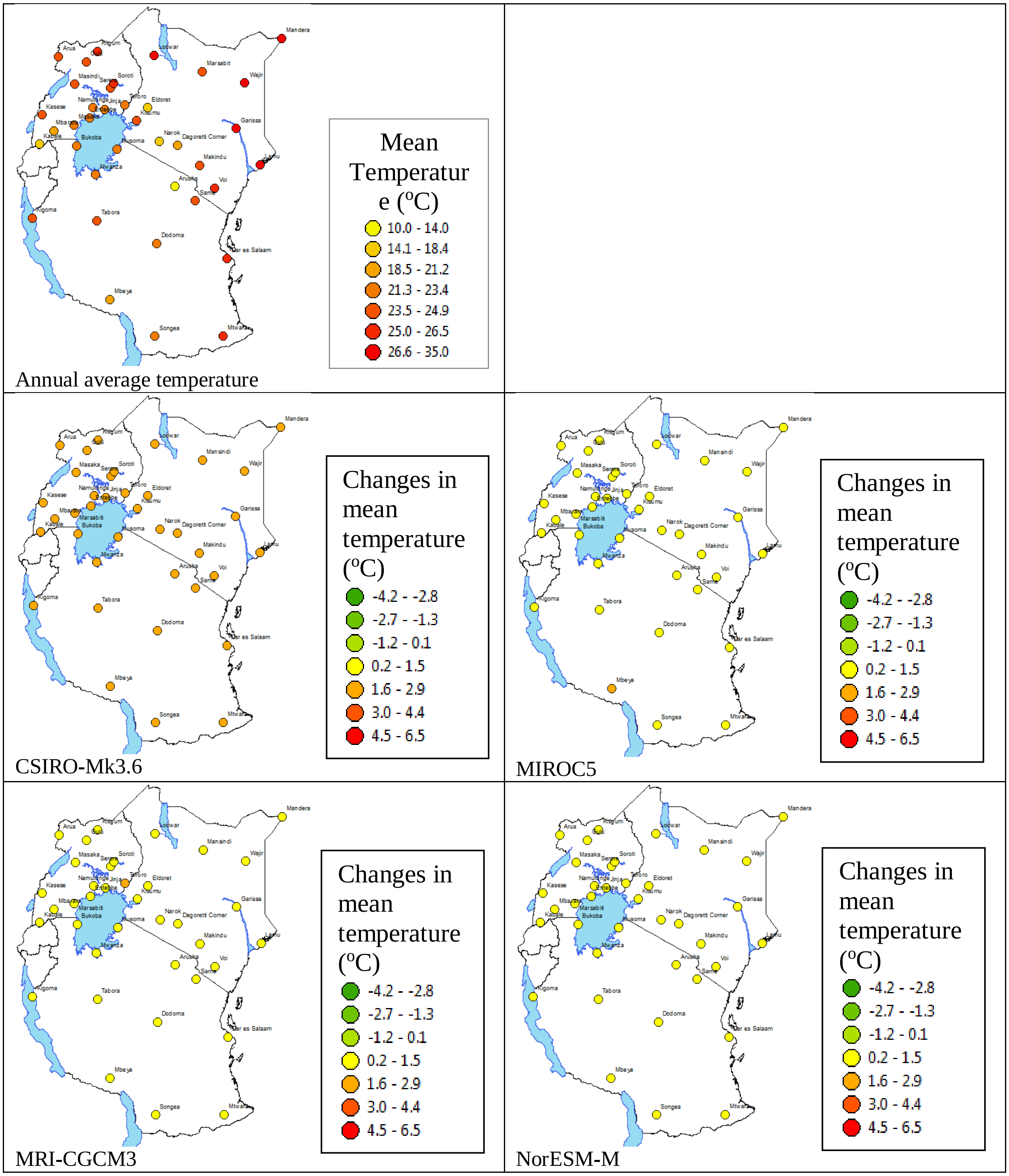


Figure 3. 13 Historical mean annual temperature and relative changes of mean annual temperatures for the 2070s for RCP4.5 for four GCMs

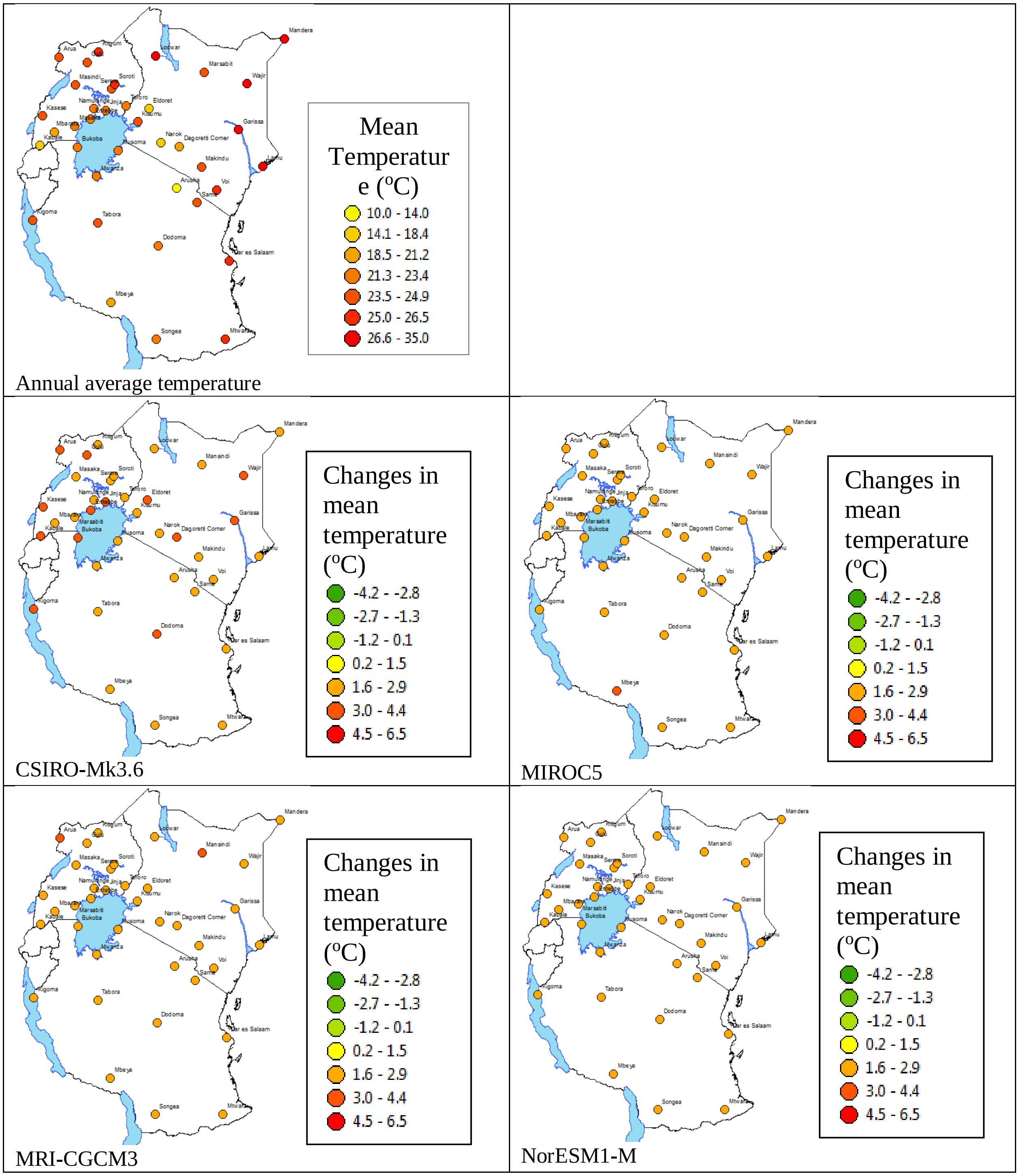


Figure 3. 14 Historical mean annual temperature and relative changes of mean annual temperatures for the 2070s for RCP8.5 for four GCMs

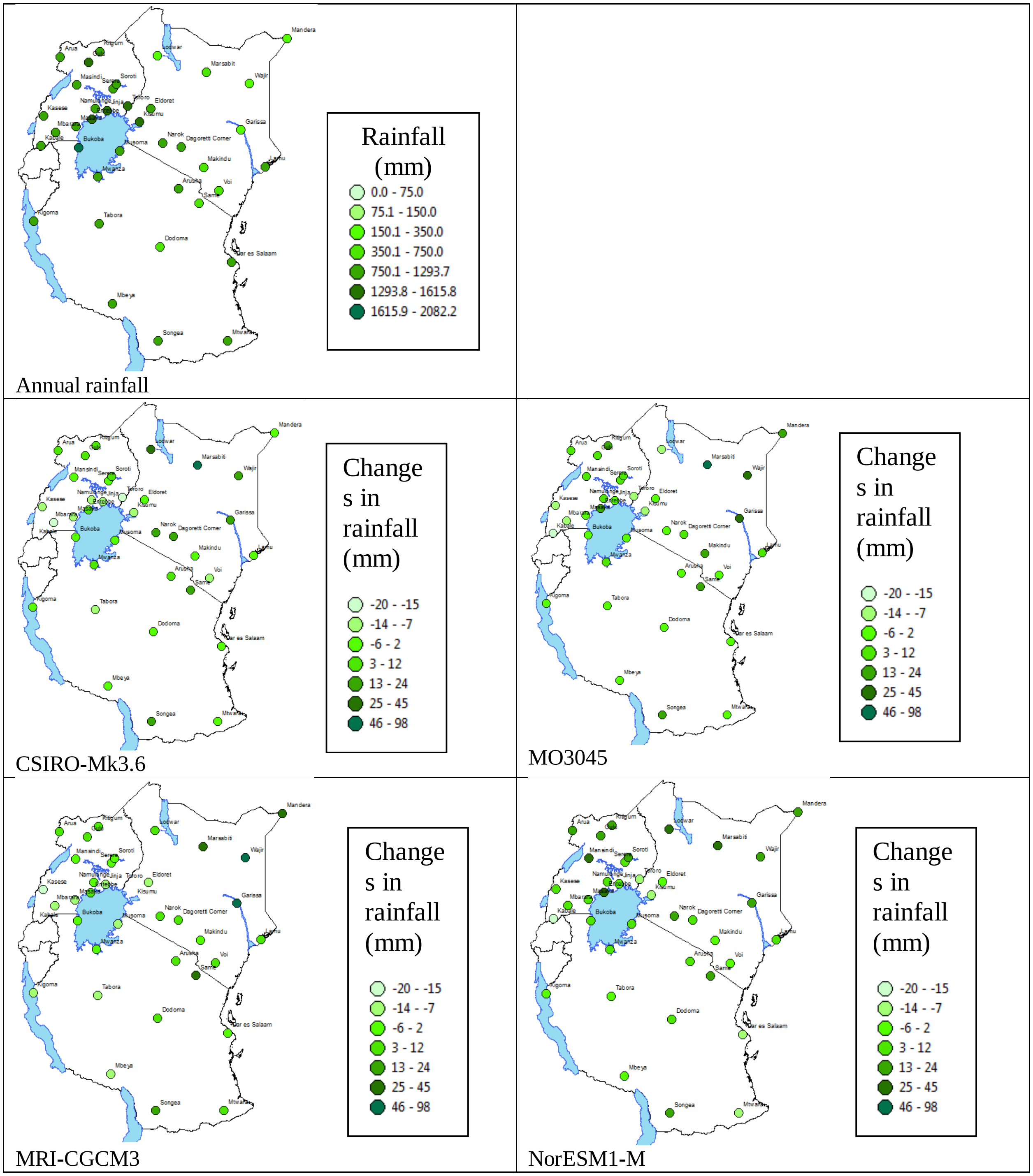


Figure 3. 15 Historical mean annual rainfall and relative changes of mean annual rainfall for the 2030s for RCP4.5 for four GCMs

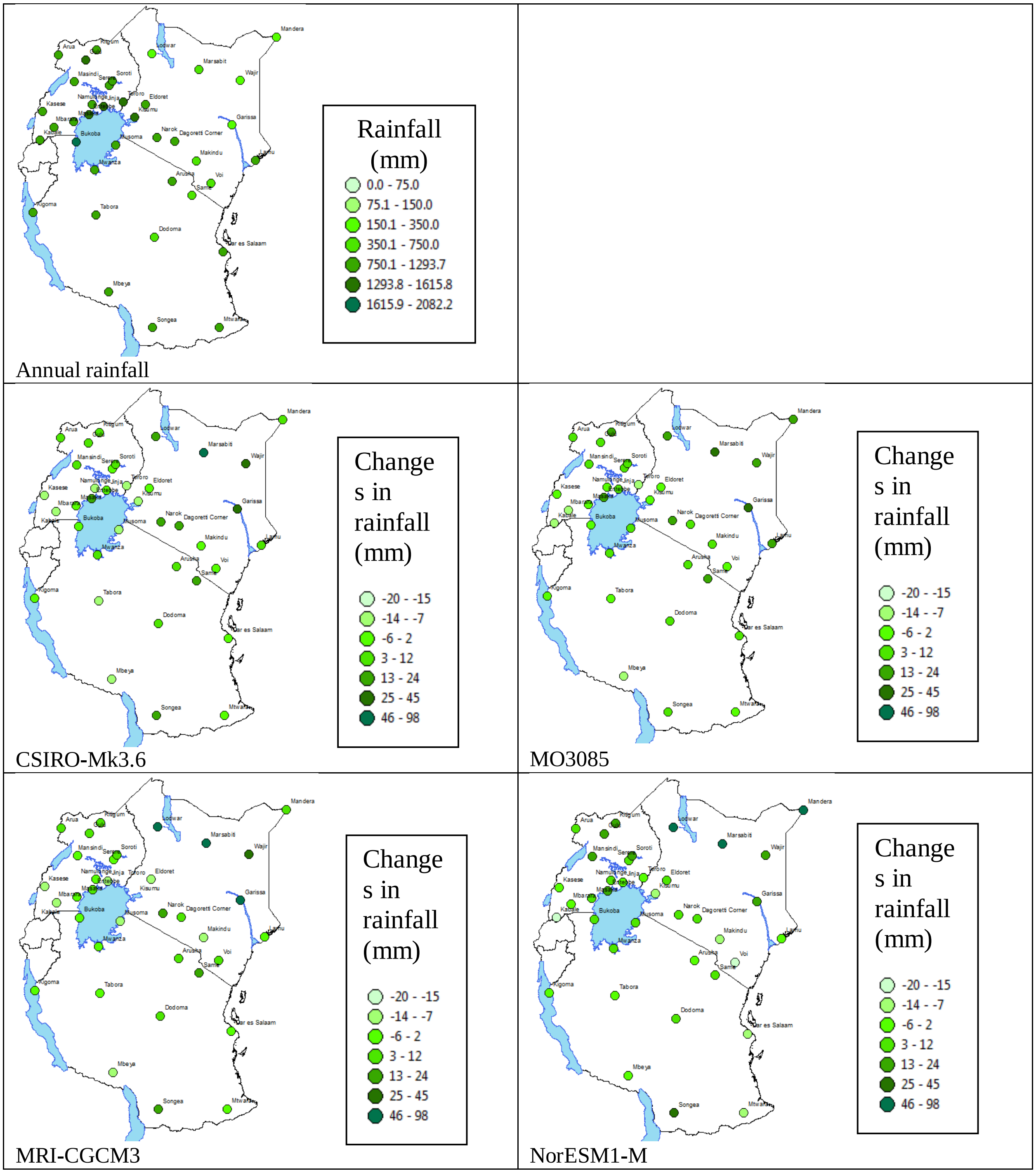


Figure 3. 16 Historical mean annual rainfall and relative changes of mean annual rainfall for the 2030s for RCP8.5 for four GCMs

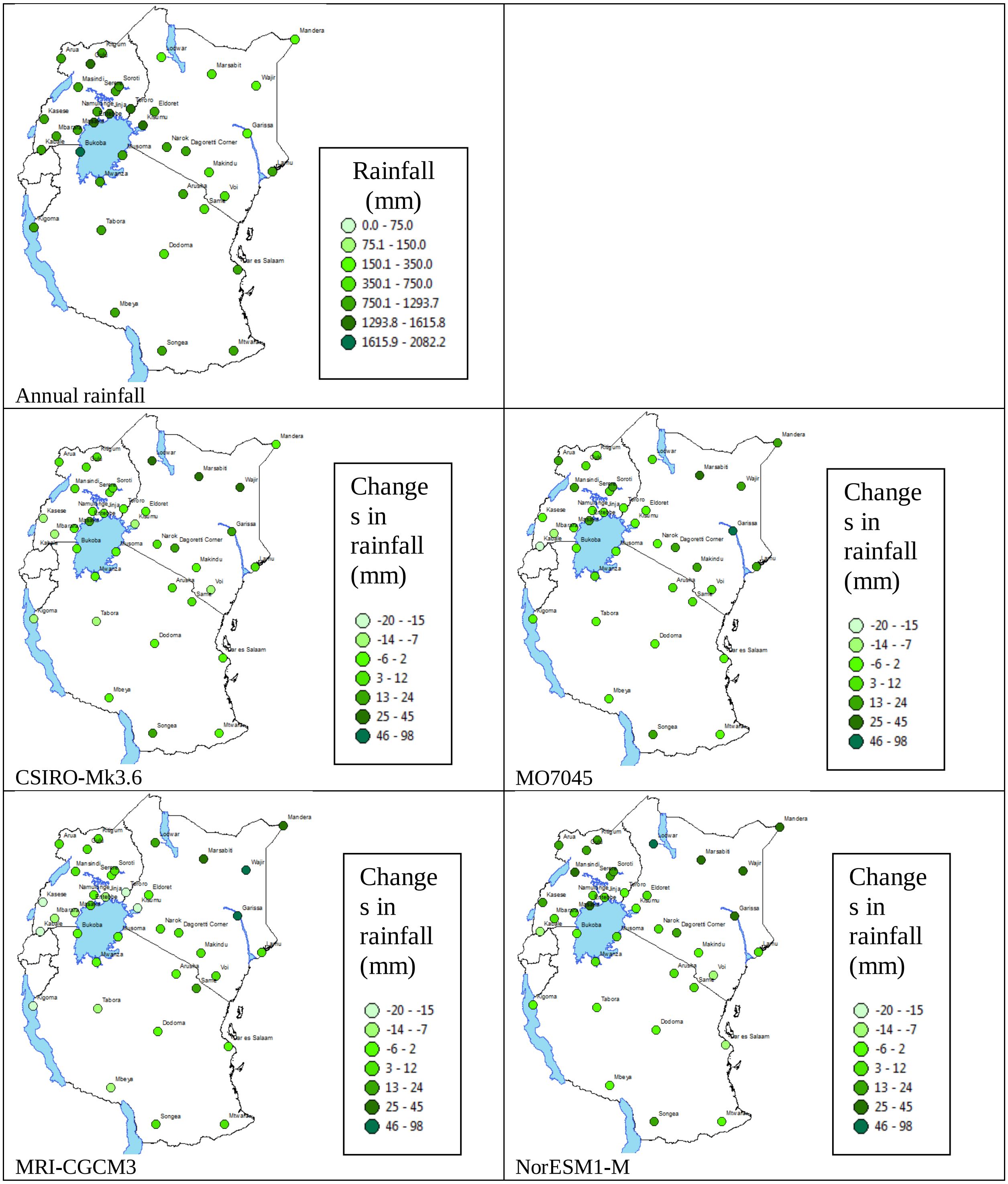


Figure 3. 17 Historical mean annual rainfall and relative changes of mean annual rainfall for the 2070s for RCP4.5 for four GCMs

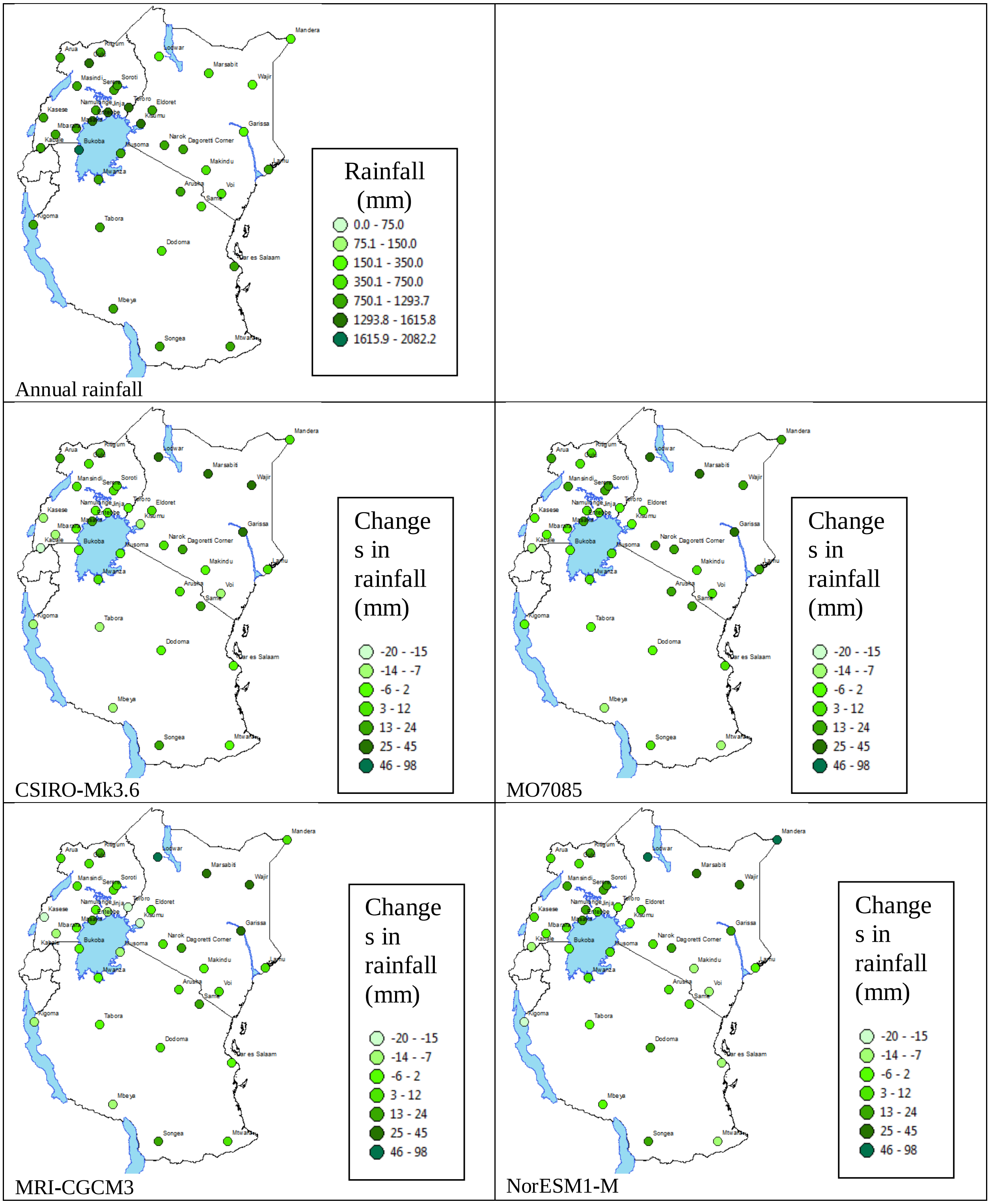


Figure 3. 18 Historical mean annual rainfall and relative changes of mean annual rainfall for the 2070s for RCP8.5 for four GCMs

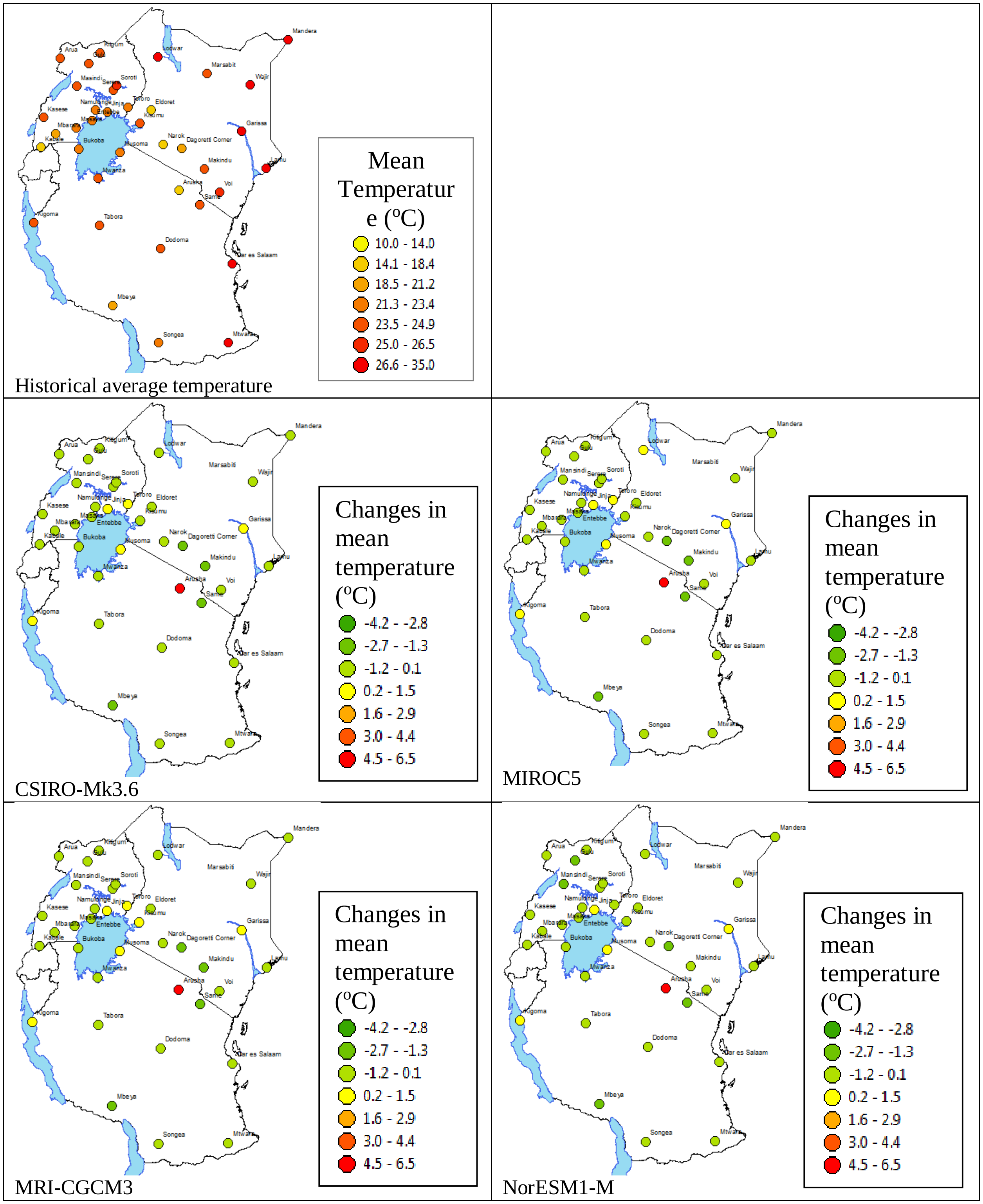


Figure 3. 19 Historical mean seasonal temperature and relative changes of mean temperatures for August to December for the 2030s for RCP4.5 for four GCMs.

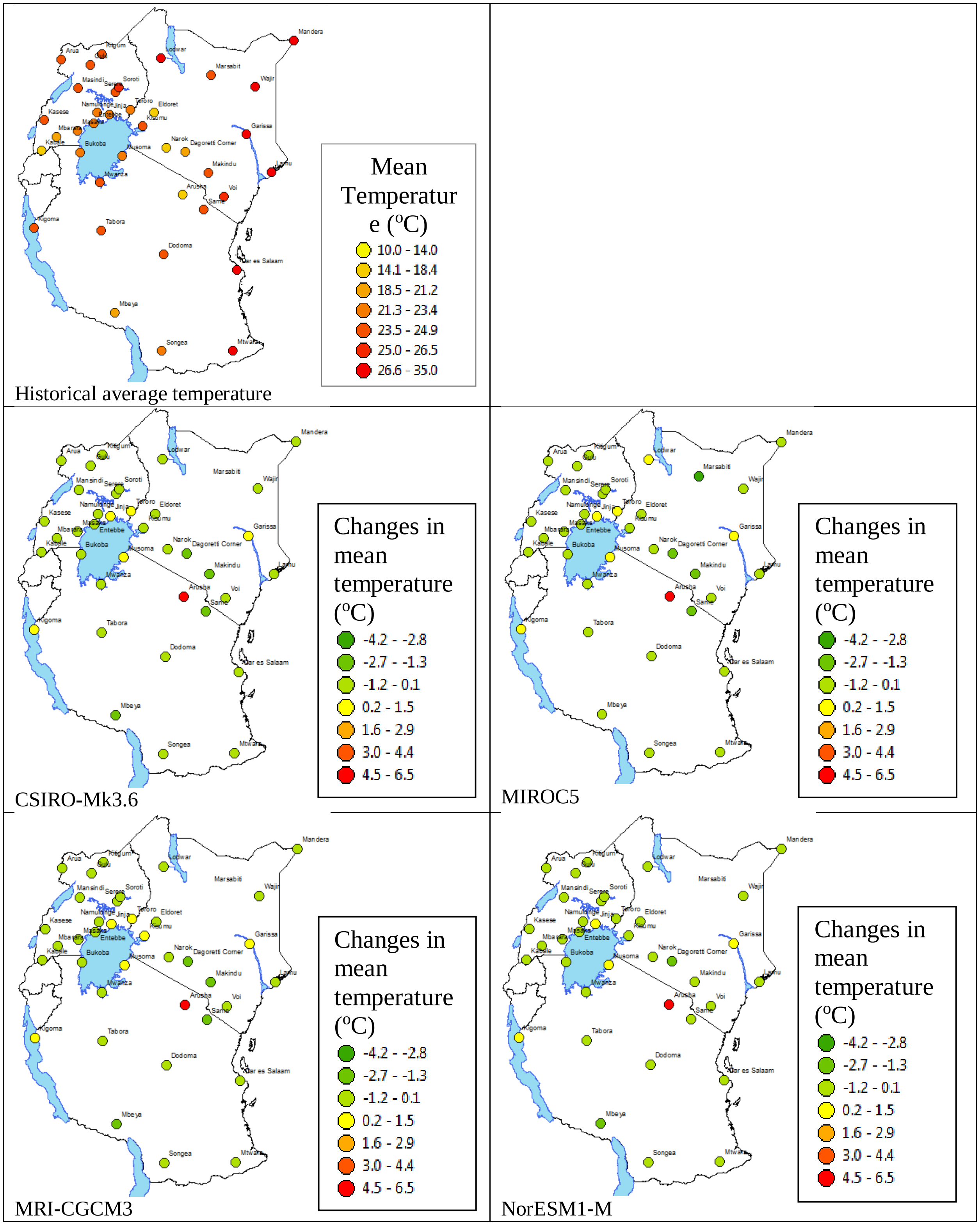


Figure 3. 20 Historical mean seasonal temperature and relative changes of mean temperatures for August to December for the 2030s for RCP8.5 for four GCMs

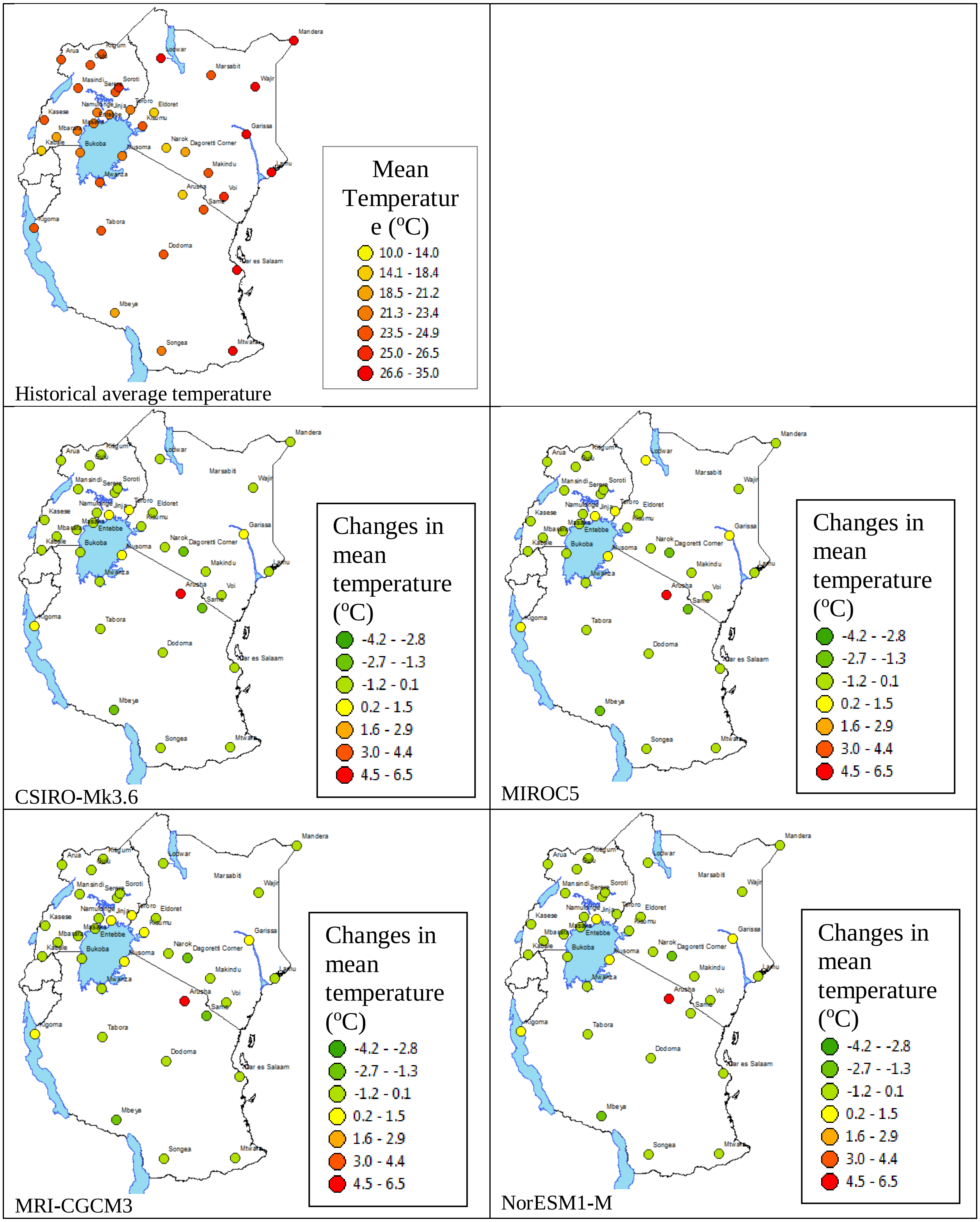


Figure 3. 21 Historical mean seasonal temperature and relative changes of mean temperatures for August to December for the 2070s for RCP4.5 for four GCMs

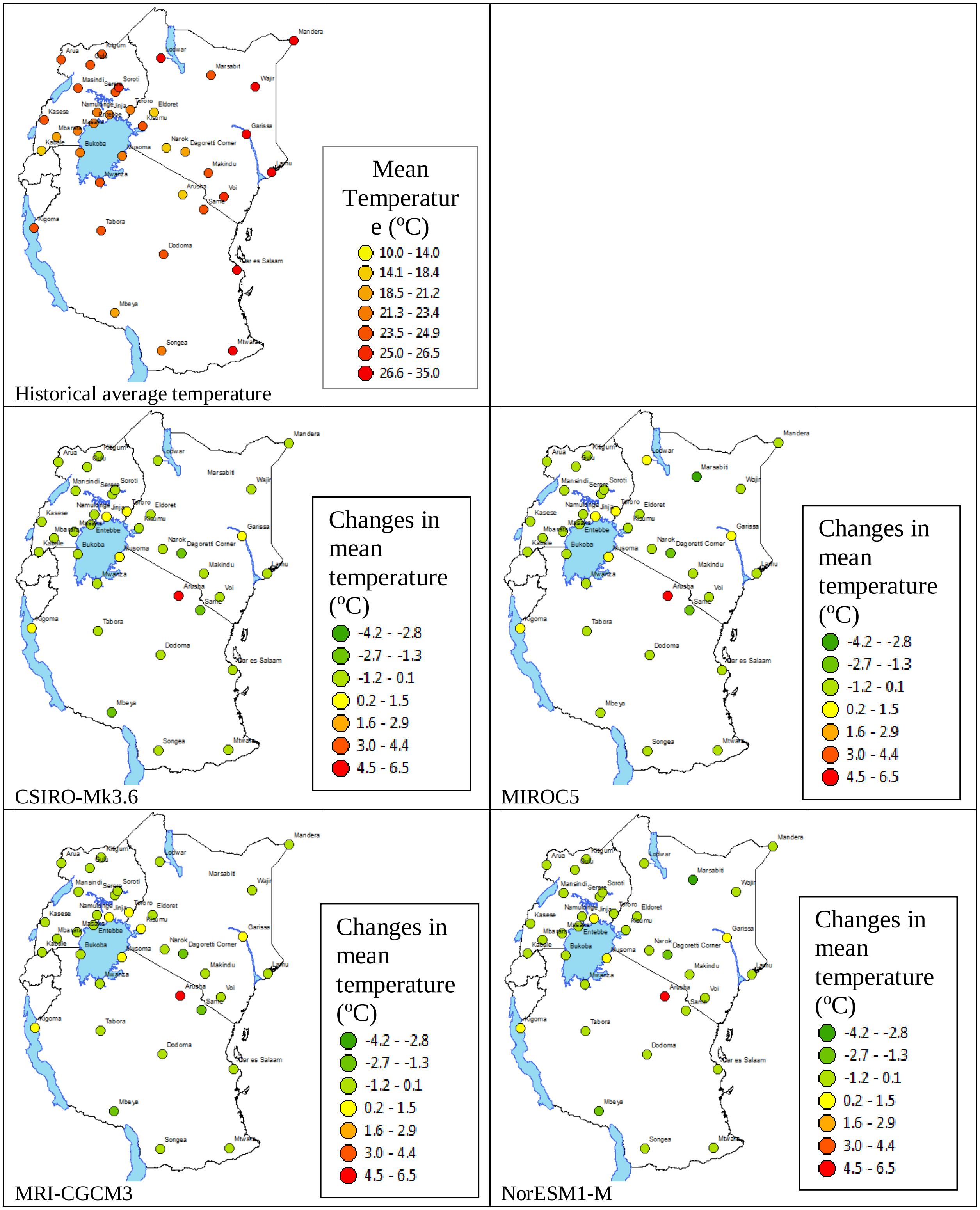


Figure 3. 22 Historical mean seasonal temperature and relative changes of mean temperatures for August to December for the 2070s for RCP8.5 for four GCMs

3.3.2.3 Future crop yields

3.3.2.3.1 Historical sweet potato yield

The magnitudes of highest yield have a range of 83-100 t/ha for both seasons in most parts of Uganda and north-western parts of Tanzania for NASPOT 1 (Figures 3.8 a-e), NASPOT 10 (Figures 3.8 f-j), and NASPOT 11 (Figures3.8 p-t) and 58-62 t/ha for SPK004 (Figures 3.8 k-o). The least projected combined crop yields were recorded in the region coinciding with the eastern arm of the rift-valley for all cultivars. Generally, the crop yields increase from the southeastern parts of East Africa to the north-western regions.

NASPOT1 combined root yield for both seasons is projected to increase by more than 4t/ha in western and southern Kenya, for MRICGC3-M RCP 4.5 (Figure 3.9a). Higher NASPOT1 yields of more than 5 t/ha were projected for most parts of East Africa by MRICGC3-M RCP 8.5 (Fig 3.9b). NorESM-1 showed a smaller increase in yield of 1 t/ha for most parts of East Africa but southern and southwestern Tanzania (Figure 3.9c). There was, however, higher increase in yield for NASPOT1 in 2035 for NorESM-1 RCP8.5 than NorESM-1 RCP 4.5 although it is still less than that recorded by MRICGC3-M RCP8.5 in 2035. In the 2050s and 2070s, there are isolated regions which will have higher increases in yield of magnitude more than 10t/ha mainly in Kenya and northern Tanzania. This is the case were both GCMs MRICGC3-M (Figures 3.9 f, j) and NorESM-1 (Figures 3.9 h, i) are in agreement.

The SPK004 combined (both seasons added together) yield projections show that in the 2030s, the root yield will have minor increases in yield of about 1 t/ha with a few spots registering higher yields (Figures 3.10 a-d) for both MRICGC3-M and NorESM-1. The yield in the 2050s is projected to increase with magnitudes of not more than 3 t/ha in parts of central and southern-western Tanzania and in areas around Mt. Kilimanjaro (Figures 3.10 e-h). In the 2070s, the highest combined yield increases in SPK004 were shown by MRICGC3-M RCP 4.5 (Figure 3.10 i). There is an agreement in regions with a projected increase in yield of SPK004 for MRICGC3-M 4.5 (Figure 3.10 i), MRICGC3-M RCP 8.5 (Figure 3.10 j) and NorESM1-M RCP 4.5 (Figure 3.10 k).

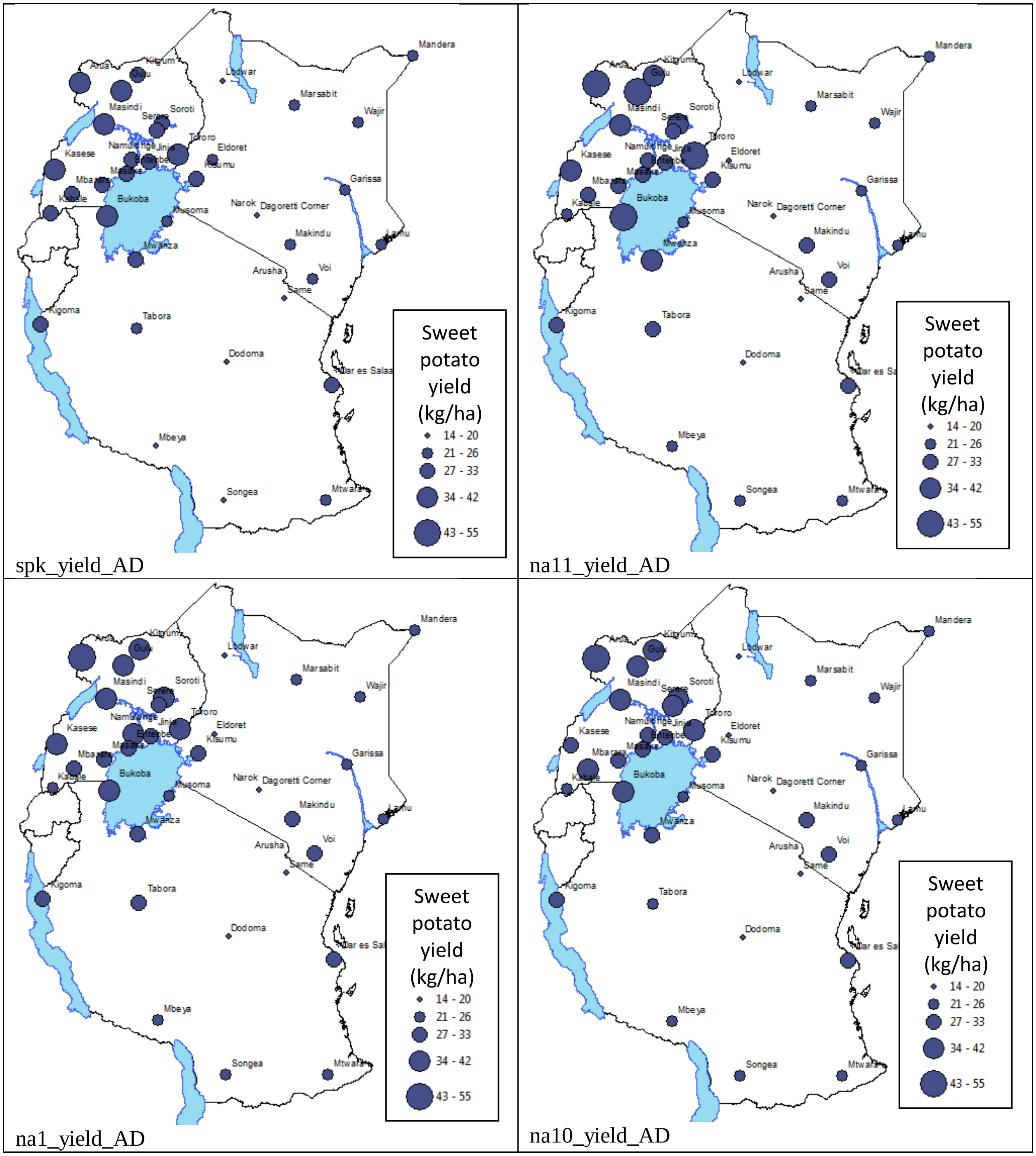


Figure 3. 23 Distribution of average sweet potato yield for the August to December season for the period 1980 - 2009

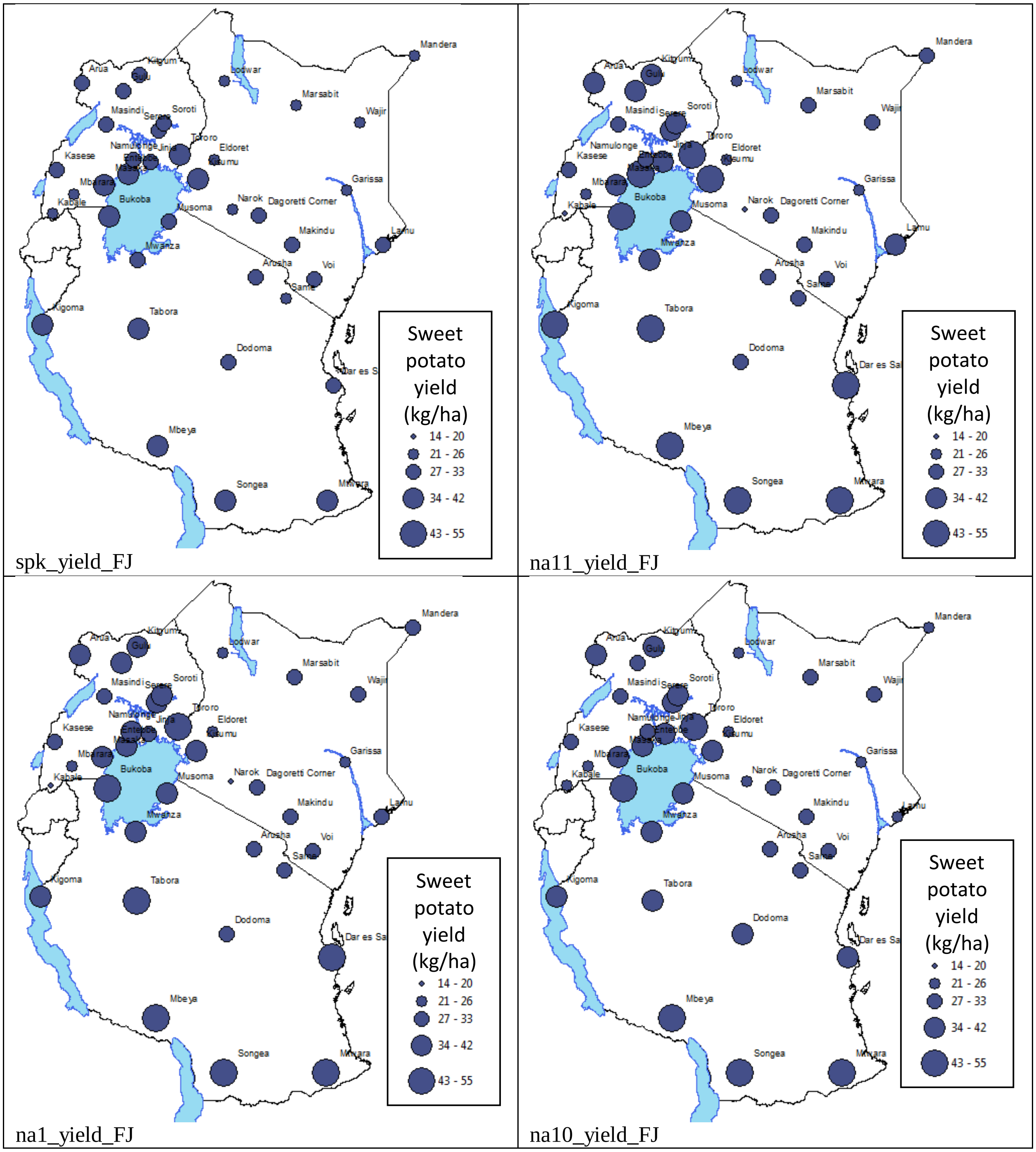


Figure 3. 24 Distribution of average sweet potato yield for the February to June season for the period 1980 - 2009

3.3.2.3.2 February-June (FMAMJ) yield projections

In the 2030s, most areas in East Africa were projected to have increases of 5 t/ha shown by RCP 8.5 for both models in some areas near Lake Turkana in Kenya (Figures 3.25, 3.26, 3.27 and 3.28). In the 2050s, most areas are projected to have increased NASPOT 1 yields with MRICGC3-M RCP 8.5 and NorESM1-M RCP 8.5 showing even higher yields. In the 2070s, similar patterns of changes in yield to those of 2055 were projected to be seen.

Most parts of East Africa were projected to receive an increase in sweet potato production in the range of 1-3 t/ha GCM (Figures). There were small projected increases in SPK004 yield in the 2050s and 2070s (Figures 3.25, 3.26, 3.27 and 3.28). Overall, the SPK004 yield will increase by 1-3 t/ha across the East African region.

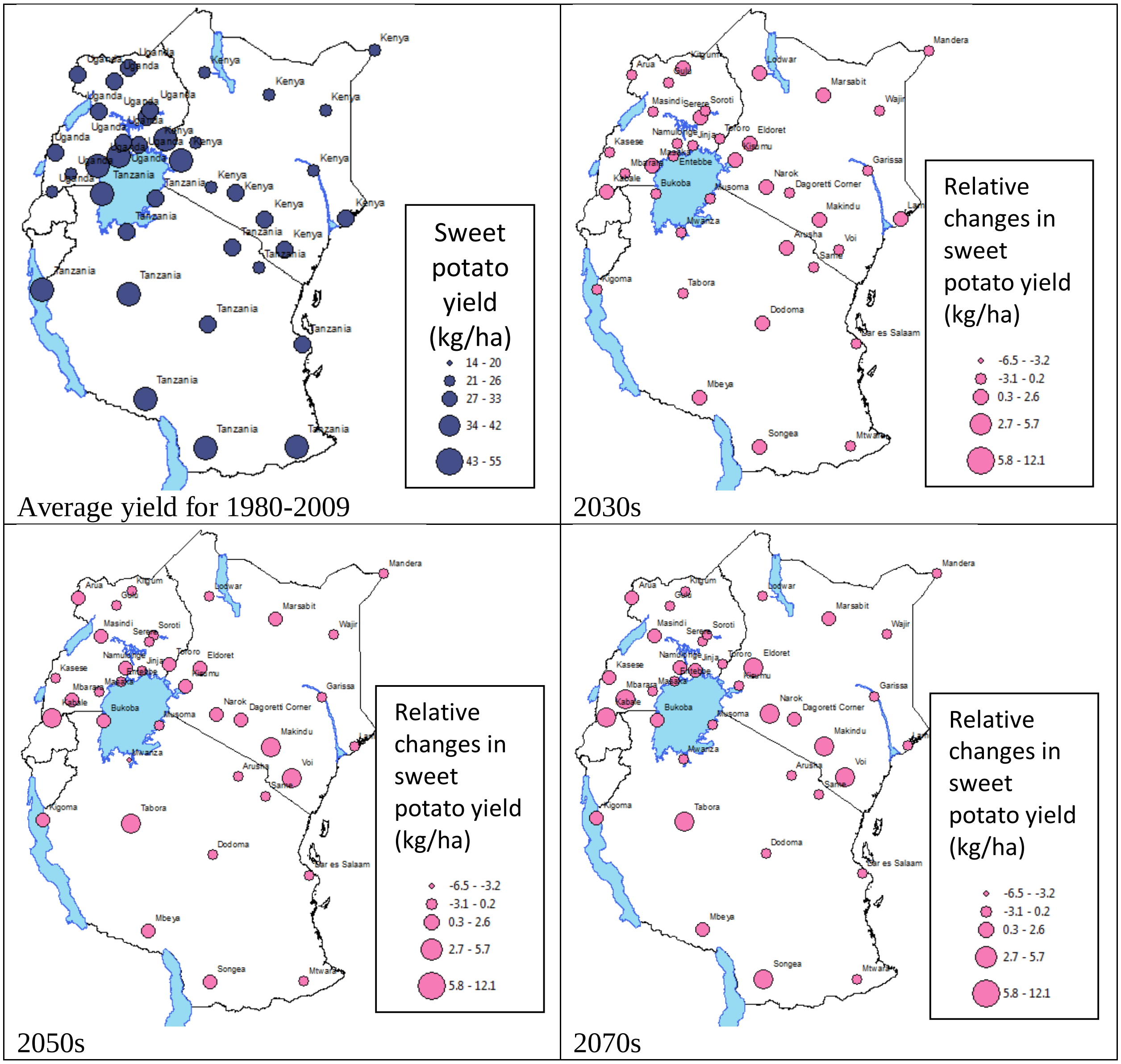


Figure 3. 25 Historical average yield and relative changes in yield of SPK 004 sweet potato cultivar for the February to June season in the 2030s, 2050s, and 2070s for RCP 4.5 for CSIRO-Mk3.6

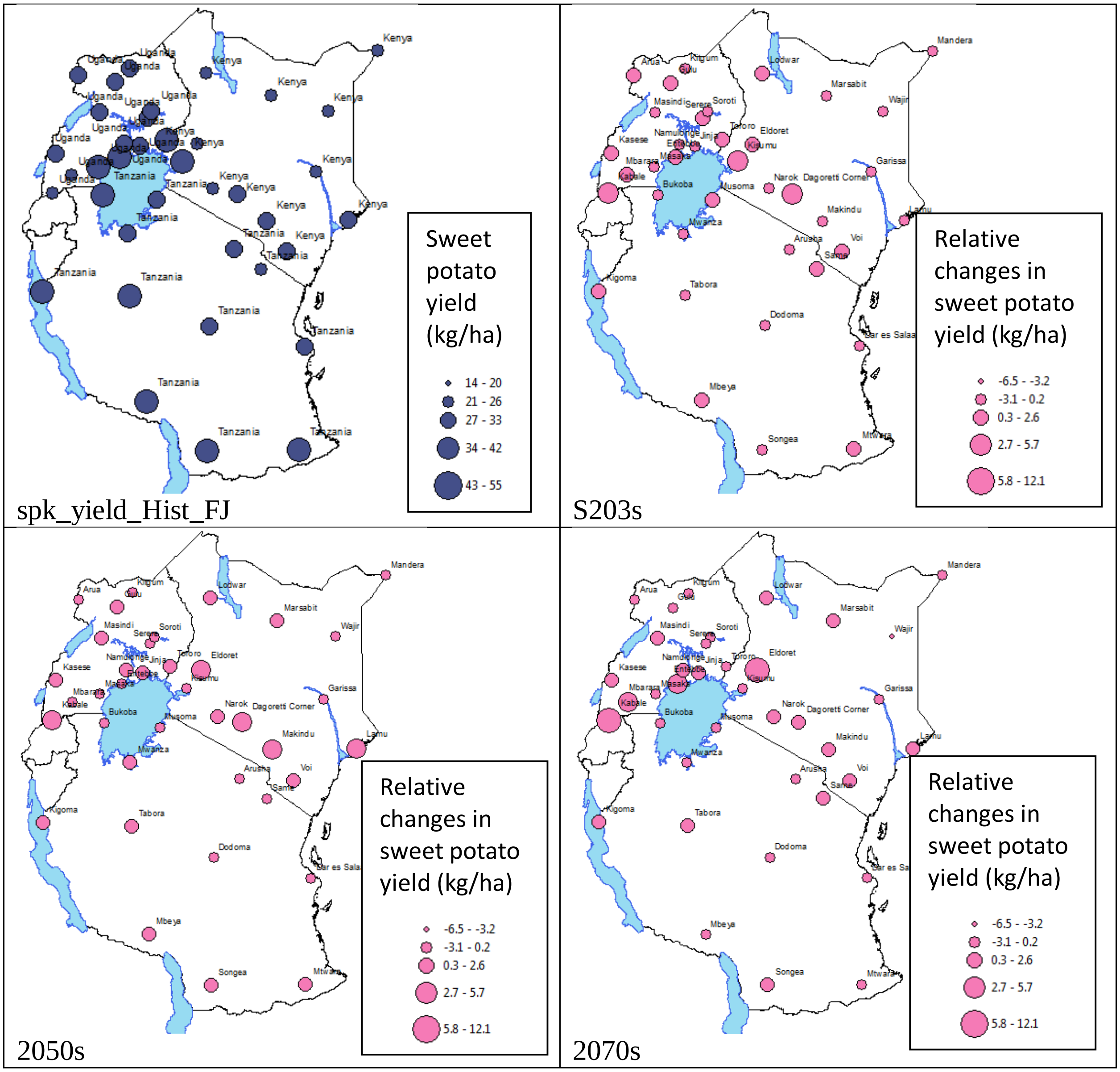


Figure 3. 26 Historical average yield and relative changes in yield of SPK 004 sweet potato cultivar for the February to June season in the 2030s, 2050s, and 2070s for RCP 8.5 for CSIRO-Mk3.6

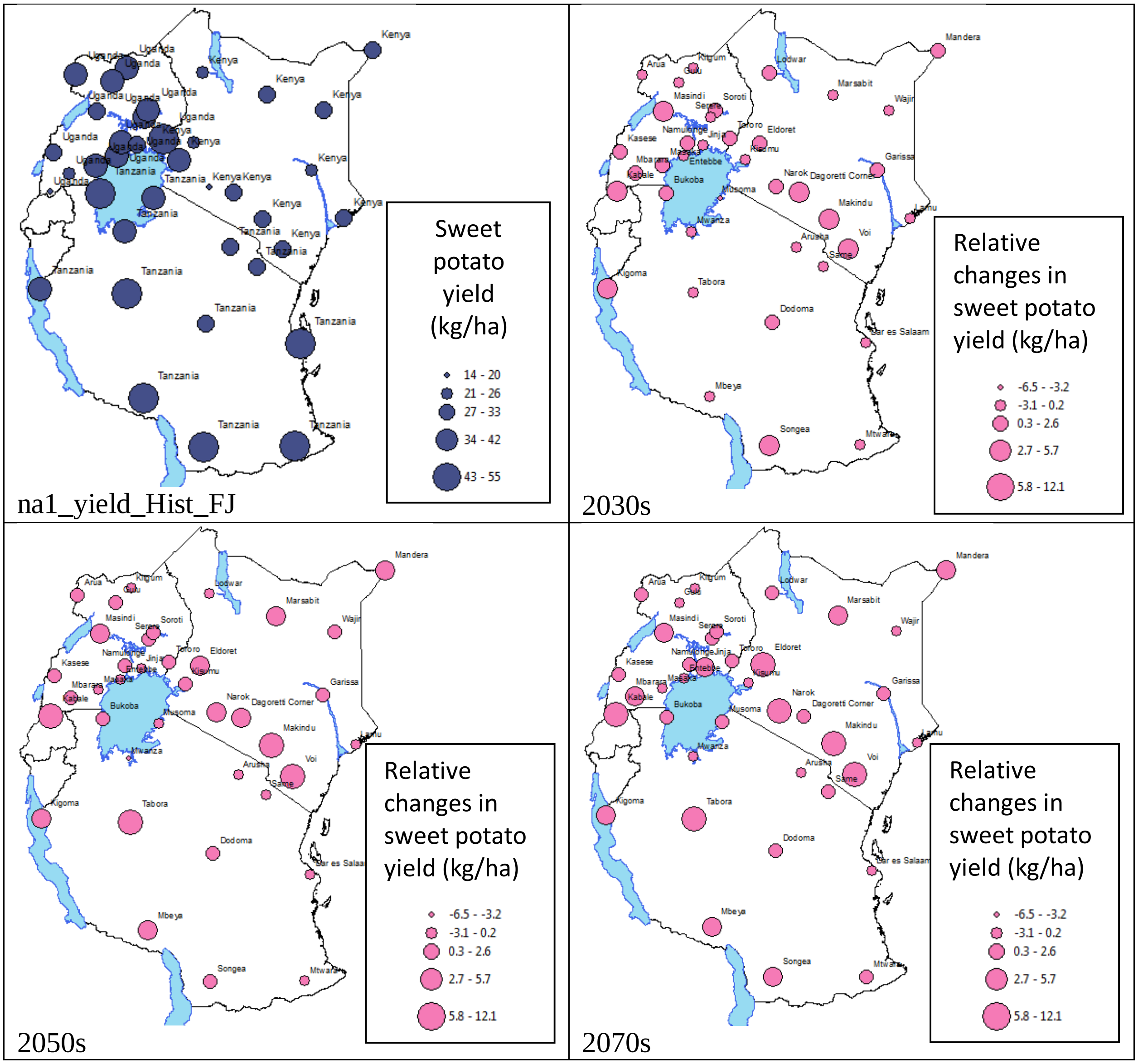


Figure 3. 27 Historical average yield and relative changes in yield of NASPOT 1 sweet potato cultivar for the February to June season in the 2030s, 2050s, and 2070s for RCP 4.5 for CSIRO-Mk3.6

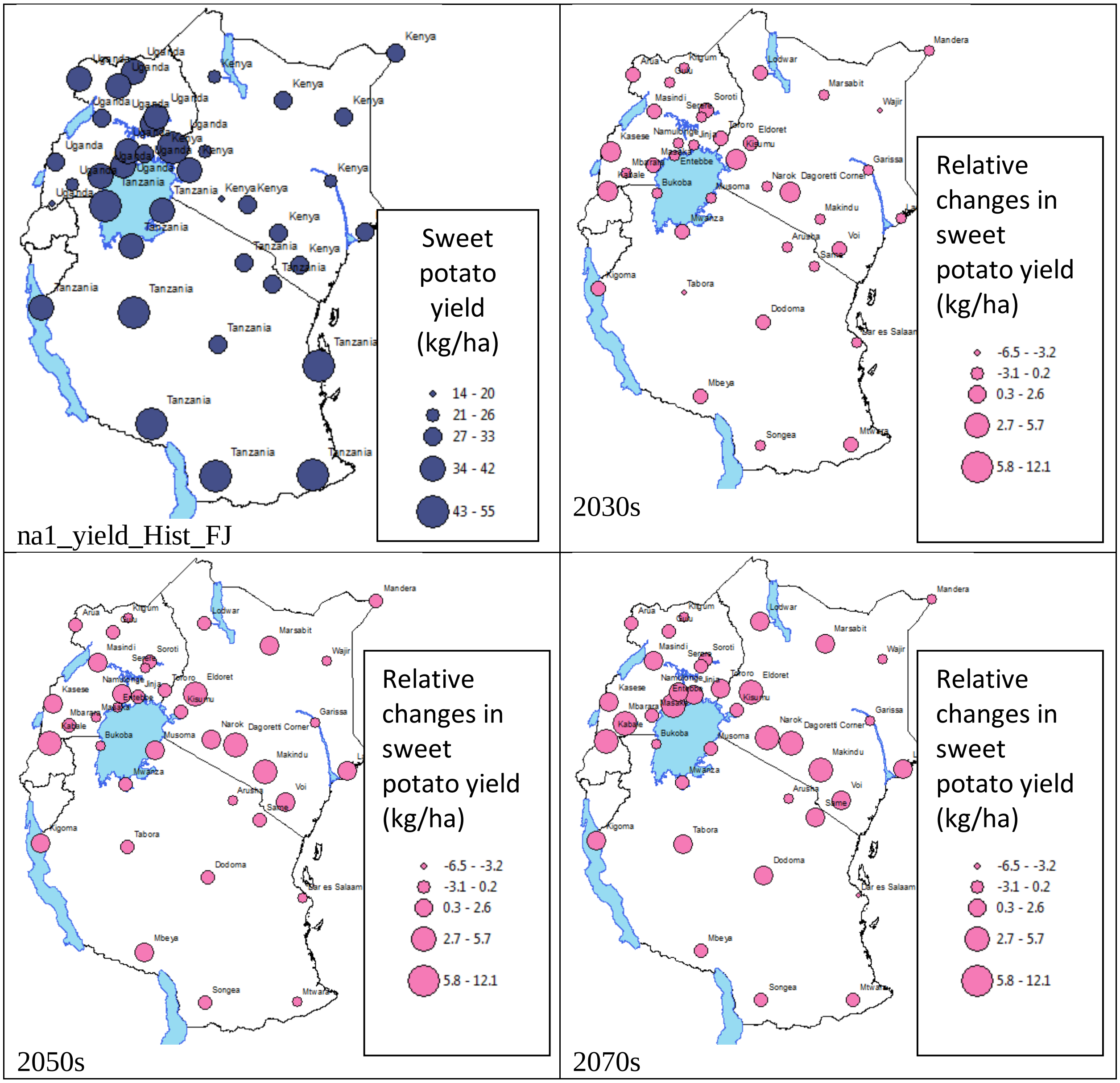


Figure 3. 28 Figure 6 Historical average yield and relative changes in yield of NASPOT 1 sweet potato cultivar for the February to June season in the 2030s, 2050s, and 2070s for RCP 8.5 for CSIRO-Mk3.6

3.3.2.3.3 August-December (ASOND) yield projections

The SPK004 root yield for 1980 – 2009 showed the lowest yield recorded for the short rains of magnitudes below 38 t/ha and largely below 29t/ha for most parts of the historical climate and control period (Figures 3.29). In the 2030s, the whole of the East African region is projected to record increases in sweet potato of at least 1 t/ha with a few areas near the Kenya – Tanzania border recording 2-4 t/ha (Figures 3.29 and 3.30). In the 2050s and 2070s, most areas across East Africa will register an increase in SPK004 of at least 1 t/ha. Areas along the Kenya – Tanzania border are projected to receive a higher projection of 4t/ha or more (Figures 3.29 and 3.30).

The NASPOT 1 and SPK004 root yield in 1980 - 2009 showed increasing yields from the south-east to north-west direction with largest increases of yields of 44-47 t/ha in some parts of Uganda (Figure 3.29). In the 2030s, the NASPOT 1 yields are projected to increase across central parts of East Africa with higher increases shown by MRICGC3-M RCP4.5 and 8.5 (Figures 3.31 and 3.32). The NorESM1-M shows very little increase in yield. In the 2050s, NASPOT 1 yields are projected to increase largely in most parts of Kenya and north-eastern Tanzania for both scenarios of MRICGC3-M (Figures 3.31 and 3.32). In the 2070s, the NASPOT 1 yields are projected to increase highest across most of the East African region with the largest increase of more than 10 t/ha root yields in south0-western Kenya and part of northern Tanzania (Figure 3.32). The southern part of Tanzania and northeastern parts of Kenya will experience a reduction in yields to the magnitude of 7-15 t/ha.

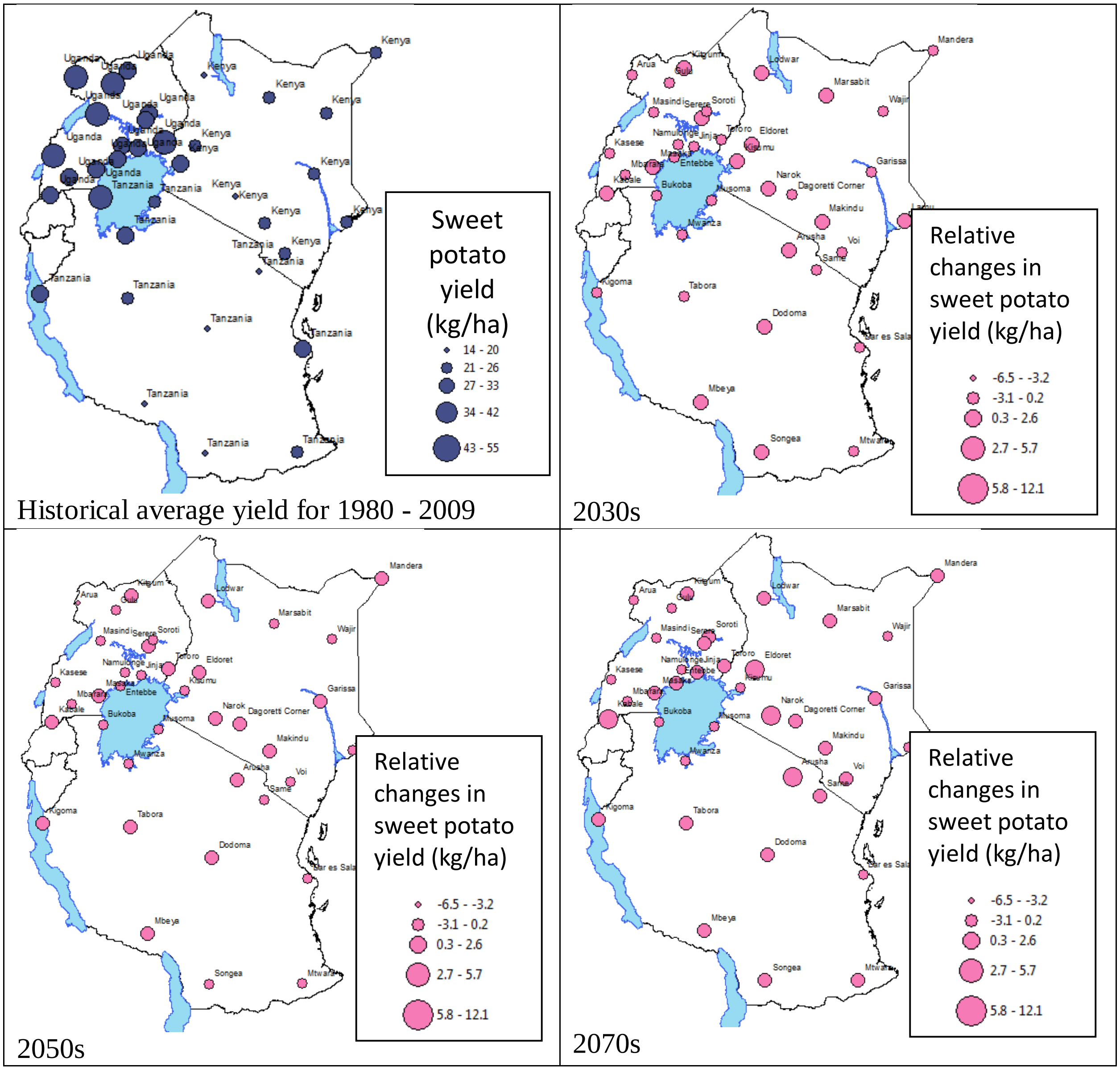


Figure 3. 29 Historical average yield and relative changes in yield of SPK 004 sweet potato cultivar for the August - December season in the 2030s, 2050s, and 2070s for RCP 4.5 for CSIRO-Mk3.6

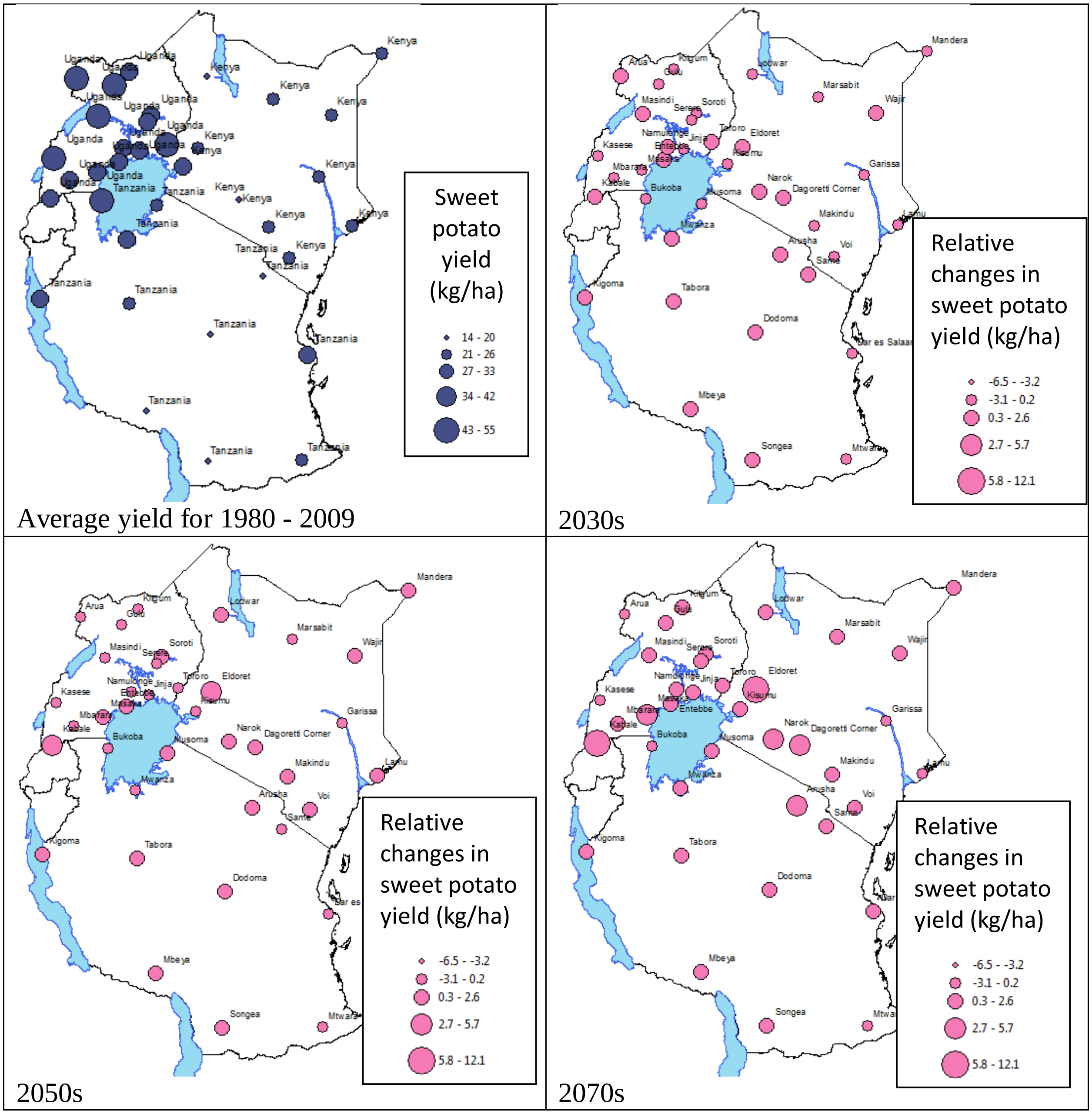


Figure 3. 30 Historical average yield and relative changes in yield of SPK 004 sweet potato cultivar for the August - December season in the 2030s, 2050s, and 2070s for RCP 8.5 for CSIRO-Mk3.6

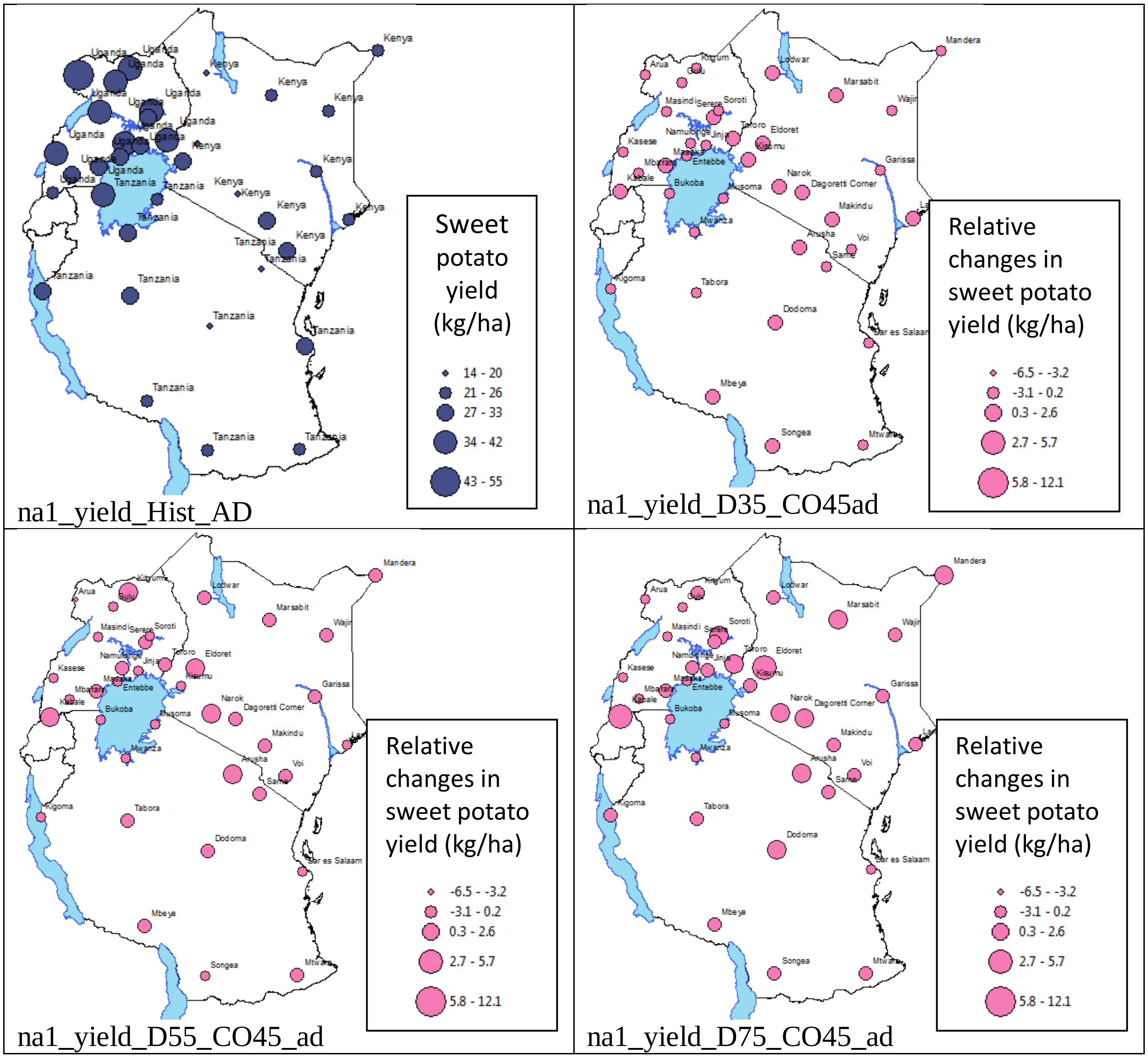


Figure 3. 31 Historical average yield and relative changes in yield of NASPOT 1 sweet potato cultivar for the August - December season in the 2030s, 2050s, and 2070s under RCP 4.5 for CSIRO-Mk3.6

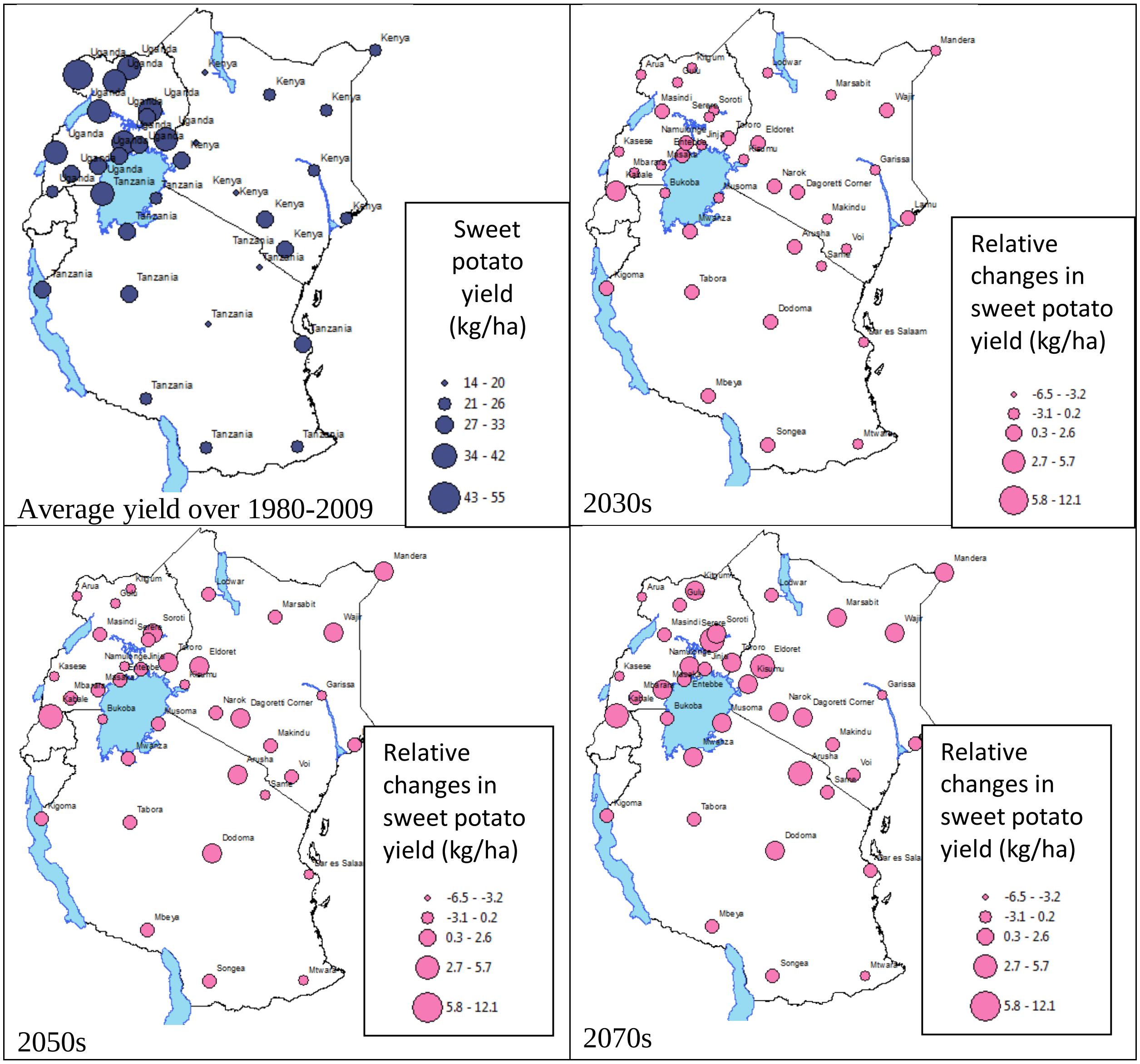


Figure 3. 32 Historical average yield and relative changes in yield of NASPOT 1 sweet potato cultivar for the August - December season in the 2030s, 2050s, and 2070s for RCP 8.5 for CSIRO-Mk3.6

3.4. Discussion

This section attempted to answer the question, “why does all this matter?” The results presented in the previous section were compared with past work and highlighted the contribution that the study was set to achieve. The nature and accuracy of the results largely depended on the quality of data used and the precision of both the General Circulation Models and the crop model employed in the study. These challenges were also discussed in the preceding paragraph. And finally, another perspective on the robustness of the agricultural production problem was put in a broader context by highlighting the role of socio-economic factors in impacting production, much as this study did not consider such factors.

The reduction in precipitation during the long rains season (Feb-June) and its increase during the short rains season (August-December) as reported from the trend analysis of the last 30 years is in agreement with findings by the Famine Early Warning Systems Network (FEWSNet, 2010; 2012) who reported a reduction in the length of the long rains season and increase in length of the short rains season. For temperatures, on the other hand, the present study found an increase in the mean temperatures in the range 0^0C-1.5^0C which averagely gets to about 0.7^0C in both rain seasons. This increase is almost similar to the 0.8^0C increase that was reported in FEWSNet, 2010:2012) which is a sign of consistency of the climate data sources employed in the present study. The projected trends were consistent with the observed trends. The GCMs captured well the seasonal variation in climate.

The spatial and temporal variation of seasonal yields trends showed that the increase in yields coincided with areas which showed increases in precipitation and temperatures which confirm the importance of availability and requirement of moisture and high temperatures for the optimal growth and productivity of sweet potatoes. However, the timing of these changes in precipitation and temperatures is critical to the yields obtained at end the end of the season as (Loretan et al., 1994; Togari, 1950; Villordon et al., 2012) emphasized that the early-season (first 20 days) growing environment directly and significantly impacts on storage root initiation and thus final yield. Whereas increases in temperatures are largely good but there can be some impacts because temperature stress can limit on crop growth and development (Wrigley, 1994) thereby causing irreversible damages to the plant processes and thus affecting final yield.

Sensitivity analysis showed that SPOTCOMS was sensitive to increase in precipitation and temperature for all the four sweet potato cultivars, NASPOT 1, NASPOT 10 0, NASPOT 11 and SPK004. SPOTCOMS did not clearly show a threshold upon which sweet potato growth would be inhibited. Most of the graphs for the three locations in Uganda, Kenya, and Tanzania showed an increasing trend of crop yields with increasing precipitation and temperature which will require further refinement of SPOTCOMs to include thresholds. The validity of our analysis was however confirmed when we clearly plotted graphs of daily maximum and minimum temperatures for a scenario when the temperatures were increased by 5^0C for the three locations (Figure 3.15) to have an idea on the highest temperatures reached. The graphs showed that all the three locations, the temperatures never exceed 35^0C. Studies have not yet been conducted to fully examine the effect of temperatures on sweet potato growth but (Spence & Humphries, 1972), obtained optimum storage root formation and development was obtained when the soil temperature was 25^0C, whereas soil temperatures of 15^0C and 35^0C were inhibitory to storage root formation when they were working with rooted single leaves of sweet potatoes. Therefore, at about 35^0C, sweet potato growth is most likely to still be taking place.

Future climate projections from Global Climate Models showed mixed results for precipitation and more distinct results for temperatures. For example, a large number of regions in

East Africa showed increases in annual precipitation of more than 50mm by MRICGC 3-M, the wettest GCM and a similar magnitude of the decrease in precipitation by NorESM-1 which is the driest GCM. These results were projected to continue in 2030s, 2050s, and 2070s. On the other hand, temperatures in the region were projected to rise by 0.8^0C, 1.2^0C and more than 3^0C in 2030s, 2050s, 2070s respective which are in agreement with previous work by (Cook & Vizy, 2013; FEWSNET, 2010, 2012; IPCC, 2013). The projections further showed more increases in the short rains then the long rains for all the three future time slices, findings which are in agreement with results from previous studies which reported shortening of long rains growing season and lengthening of short rains season (FEWSNET, 2010, 2012; IPCC, 2013).

The projected increase in sweet potato yield in the region coincided with areas that experience increases in precipitation and temperature. Models with larger radiative forcing of RCP8.5 showed an overall higher increase in precipitation, temperatures and therefore higher increases in sweet potato yield. All the four cultivars (NASPOT 1, NASPOT 10 0, SPK004 and NASPOT 11) showed similar spatial distribution of yields but SPK004 had lower yields for both historical and projected future periods. This pattern of magnitudes of yields was consistent with the observations made in chapter two where SPK004 was the lower yielding cultivar of the four. Overall, sweet potato root yield increases of 7 t/ha, 10 t/ha and more than 20 t/ha were projected for 2030s, 2050s, and 2070s.

This study was the first of its kind in the region and therefore there were no previous studies to use compare with the results on projected yields presented here. But using the Irish potato modeling work, a study involving two GCMs for rainfed conditions in the United States; the Canadian Centre Climate Model Scenario (CCGS) suggested an increase in potato yield, and the Hadley Centre Model Scenario (HGCS) suggested a decrease in yield (Tubiello et al. (2002).

Another simulation study with a potato model suggested a reduction of the growing season with climate change (Holden and Brereton, 2006; Stockle et al., 2010).

Understanding the magnitude of the impacts of climate change and variability on sweet potato production is complicated by the interaction of numerous biophysical and socioeconomic factors. This study has attempted to focus on the weather/climate/seasonal factors including temperature, precipitation and seasonality, and crop factors, namely crop type and crop yield. There are many other factors which need to be considered in order to address and even understand the entire problem facing crop production and agriculture. Other factors include: extreme weather events; elevation/altitude; crop price; agricultural factors such as farm size, irrigation, agricultural expenditure, labor, herbicide/insecticide and equipment; household demographic and socioeconomic factors such as household size, composition, food consumption pattern, income, water and sanitation, aggregate income, expenditure, livelihood pattern, off-farm income, livestock rearing, and maternal education, among others); and individual factors such as sex, age, morbidity, and diet.

Previous studies have combined climate, crop and economic models to examine the impact of climate change on agricultural production and food security, but results have varied widely due to differences in models, scenarios and input data (Rosenzweig and Parry 1994, Nelson et al 2010). Interdisciplinary studies based on primary data at a household level are urgently required to guide effective adaptation, particularly for rural subsistence farmers. There is need to use data from all these factors in order to develop robust statistical methods to establish and validate causal links, quantify impacts, and make reliable predictions that can guide evidence-based health interventions in the future.

3.5 Conclusion

This chapter has presented historical trends of rainfall, temperature and sweet potato yields for the period 1980-2009. Climate variability was found to be characterized by a reduction in intensity of the long rains, increase in rainfall intensity of the short rains and increase in temperatures by more than 1 degree in the last three decades. The corresponding sweet potato yields were also reported to increase with increasing precipitation and temperature. The sensitivity analysis showed that the model we have developed for East Africa can be used to test the impact of climate and other parameters on sweet potato production.

The study has quantified the impact of climate change on sweet potato production for the East African region. As one of the main staples of the region, sweet potato production is projected to largely increase in future time frames in the century. This implies that with careful attention given to the good management of farming of the sweet potatoes, the high production would significantly contribute to the projected increase in population. The people of East Africa will also have to optimize the use of sweet potato vegetative and root production in order to be able to consume most nutrients from both the vegetative parts and the roots.

Just like most studies, the modeling tool employed in this study had some limitations and will need further refinement. For example, there is need to include temperature thresholds within the model, the soil water balance model employed in SPOTCOMs needs to be further developed and the readily available water needs further development. The soil module employed in the model will also need be improved to include the different soil profile layers similar to those used in the Decision Support System for Agronomical Tool (DSSAT) crop models (J. W. Jones et al., 2003).

For optimal use of the results of this study, all key stakeholders have a role to play from governments to research institutions, to private sector organizations and the donor community.

Some of the major challenges experienced during the execution of the research were poor data quality mainly the lack of good observation records for both climate and sweet potatoes, and generally limited studies of the relationship of climate on sweet potatoes. These constraints are some of the major stumbling blocks to further research and therefore, this study recommends more future research on generally all root tubers.

Future follow-up work that is proposed will include the testing, calibration, and evaluation of SPOTCOMS across several locations across East Africa followed by a further assessment of the impact of environmental factors on sweet potato production. Secondly, this study needs to be extended to other sweet potato cultivars compared to the four used in this study. Also, there is need to use several other gridded climate datasets in running SPOTCOMS in order to be confident of the variation in the results.

CHAPTER 4.

SUMMARY AND CONCLUSION

This research assessed the impact of climate variability and change on sweet potato production in East Africa by following four major steps. The first step was to develop a modeling framework for use in a deterministic sweet potato crop model, SPOTCOMS, for East Africa; the second step was to analyze trends of historical climate and sweet potato root yields for the historical period 1980-2009; and the third step was to study developed stochastically generated current, near future 2030s, mid-future 2050s and distant future 2070s climate data scenarios for East Africa using two representative concentration pathways 4.5 and 8.5 for four Global Climate Models, CSIRO, MIROC5, MRICGC3-M and NorESM-1; and finally, the fourth step was to estimate the impact of projected future climate change on sweet potato production using SPOTCOMS model.

Some of the major achievements of this study was the determination of the sweet potato crop coefficients required for running SPOTCOMS model. The field experiments conducted at Namulonge across the two seasons in 2012 and 2013 provided the required dataset on the growth of sweet potato that made it possible to determine the coefficients. Whereas this was done at only one location under two seasons, it was recommended that follow-up studies be conducted across the whole East Africa region for more sweet potato cultivars including the four cultivars used in this study. This study was conducted for four representative high yielding cultivars in East Africa. Two of which were non-orange cultivars (NASPOT 1 and NASPOT 11) and the other two were orange cultivars (NASPOT 10 0 and SPK004- Kakamega). The other contribution of this study was the modification of the previous SPOTCOMS model to be able to input weather data of any size for any number of years and some other minor additions of variable outputs such as the potential evapotranspiration (ET), actual evapotranspiration (Etc) and the root available water (rwtr). These modifications imply that SPOTCOMS can now be run for a single site for multiple seasons. And finally, this study has provided the first quantification of the impact of climate change on sweet potato production in East Africa upon which future studies can build.

Future follow-up work that is proposed will include the testing, calibration, and evaluation of SPOTCOMS across several locations across East Africa followed by a further assessment of the impact of environmental factors on sweet potato production. Secondly, this study needs to be extended to other sweet potato cultivars compared to the four used in this study. Also, there is need to use several other gridded climate datasets in running SPOTCOMS in order to be confident of the variation in the results.

For optimal use of the results of this study, all key stakeholders have a role to play from governments to research institutions, to private sector organizations and the donor community. Some of the major challenges experienced during the execution of the research were poor data quality mainly the lack of good observation records for both climate and sweet potatoes, and generally limited studies of the relationship of climate on sweet potatoes. These constraints are some of the major stumbling blocks to further research and therefore, this study recommends more future research on generally all root tubers.

Like most models, SPOTCOMS has some limitations that will require being addressed in future studies. For example, SPOTCOMS needs to be set such that it has a threshold beyond which if the temperature is exceeded, sweet potato growth would be inhibited. This has not yet been set in the model. Second, although the model is sensitive to both temperatures and soil moisture, SPOTCOMS did not appear to give a corresponding sensitivity on the actual evapotranspiration. In other words, in a case where the ETc would be elevated, the model did not show a corresponding variation in the root available water. This is one major area that requires revisiting in the model. Third, SPOTCOMS does not yet consider CO_2 intake which is known to equally affect sweet potato growth just like temperature and soil moisture. Fourth, the model does not account for the effects of weeds, pest, and diseases and therefore, the model normally tends to overestimate yield because of this weakness. Finally, the model currently uses basic soil routines and does not account for the variation of soil nutrients in the various soil profiles as has been significantly developed in other crop models such as the DSSAT crop models (J. W. Jones et al., 2003). This too will have to be worked on in the future. One major shortcoming for SPOTCOMS, which is not uncommon in another process-based crop model, is that the model does not consider the effect of pests and diseases. This, therefore, means that the assumption is made that pest and disease management was carefully implemented in the fields, although this is not normally the case in reality.

A large proportion of the cropping and rangeland area of sub-Saharan Africa is projected to see a decrease in growing season length, and most of Africa in the southern latitudes may see losses of at least 20 percent (Thornton et al., 2011). At the same time, the probability of season failure is projected to increase for all of sub-Saharan Africa, except for central Africa; in southern Africa, nearly all rain-fed agriculture below latitude 15°S is likely to fail one year out of two (Thornton et al., 2011). In terms of timing of growing season onset, Crespo et al. (2011) demonstrate that it may be possible to adapt to projected climate shifts to at least the 2050s in maize production systems in parts of southern Africa by changing planting dates.

The findings of this study provide hope as warmer climates will generally accelerate the growth and development of sweet potato, but overly cool or hot weather will also affect sweet potato productivity.

Future studies on sweet potato should look at sweet potato yield quality which is greatly related to climate variability and extreme. This should not be an exception as some studies have already been conducted on other crops, for example, Porter & Semenov (2005) showed that protein content of wheat grain responded to changes in the mean and variability of temperature and rainfall.

Future research should also focus on mixed crop-livestock systems which are prevalent in East Africa. Sweet potato is a crop which fits well in this farming system and therefore understanding how climate change and changing climate variability in the future may affect the relationship between crops and livestock is very important. The synergy between sweet potato which is a drought tolerant crop and livestock may be a good solution towards addressing impacts of projected future of climate change and variability on agriculture.

The effects of future changes in climate variability on pests, weeds, and diseases are not well understood (Gornall et al., 2010). But changes in climate variability and in the frequency of extreme events may have substantial impacts on the prevalence and distribution of pests, weeds, and sweet potato diseases. This is an area which needs further research and development especially given that the current crop-models are not capable of modeling the effect of pests, weeds, and diseases.

Food security in the East African region could be enhanced by increasing farm-based storage facilities; improving the transportation system, especially feeder roads that link food production areas and major markets; providing farmers with early warning systems; extending credit to farmers; and the use of supplementary irrigation. These socio-economic factors have been shown to be impacted by extreme climate events in rural communities in Ghana (Codjoe and Owusu, 2011).

The orange-fleshed sweet potato which is rich in vitamin A will be a valuable crop in the future. This is because the overall availability of food shows some correlation with climate variability. Lloyd et al. (2011) showed that the impact of climate change and increased climate variability on food production will have a negative impact on the prevalence of undernutrition, increasing severe stunting by 55% in East and southern Africa by the 2050s. Therefore, investing in research in crops such as sweet potato which is likely to do well in a future with projected changing climate is of paramount importance.

Since sweet potato is grown mostly by poor smallholder farmers, governments can play a crucial role in smallholder agriculture. Governments in East African countries can invest in activities such as storage, trace, processing and retailing; implementing and scaling up options that help producers to be more resilient to climate volatility, such as the use of smallholder crop insurance schemes; and establishing safety net programmes for the most vulnerable households, such as has been implemented successfully in Ethiopia (Lipper, 2011). By so doing, the governments could have helped smallholder farmers to be more resilient to the impacts of climate change on crop production.

There is a great need to improve the monitoring of local conditions, not only to provide data and information for improving our understanding and our models but also to guide effective adaptation and to provide information for yield early warning systems and locally appropriate indices for weather-based crop and livestock insurance schemes. As pointed out in this study, there a number of satellite and land-based weather data sets but they are not a replacement for land-based weather measurement. Governments need to significantly increase their investments in the area of data monitoring so that the research scientific community can conduct research with more precision.

APPENDICES

APPENDIX A: Sensitivity analysis

Table 3. 6 Summary data for Sensitivity analysis Dagoretti Corner (DC), Kenya

Combination	**Δprecip (%)**	**ΔTemp (C)**	**DC-na1-AD-yield (t/ha)**	**DC-na10-AD-yield (t/ha)**	**DC-na11-AD-yield (t/ha)**	**DC-spk-AD-yield (t/ha)**	**DC-na1-FJ-yield (t/ha)**	**DC-na10-FJ-yield (t/ha)**	**DC-na11-FJ-yield (t/ha)**	**DC-spk-FJ-yield (t/ha)**
_P-50T-5	-50	-5	7.4	7.7	7.2	9.2	9.6	9.9	9.3	11.7
_P-40T-5	-40	-5	7.5	7.8	7.3	9.3	9.9	10.3	9.6	12.3
_P-30T-5	-30	-5	8.1	8.6	6.8	10.5	10.6	11.4	10.2	12.0
_P-20T-5	-20	-5	7.9	8.2	7.7	9.7	11.6	12.5	11.2	15.3
_P-10T-5	-10	-5	8.1	8.4	7.9	10.1	13.2	14.3	12.7	17.5
P_P+0T-5	0	-5	8.4	8.7	8.2	10.5	15.4	16.7	14.7	20.4
_P+10T-5	10	-5	8.7	9.1	8.5	10.9	18.1	19.5	17.3	22.8
_P+20T-5	20	-5	9.2	9.6	8.9	11.3	20.7	22.1	20.0	24.3
_P+30T-5	30	-5	9.7	10.1	9.4	11.9	23.0	24.3	22.5	25.8
_P+40T-5	40	-5	10.2	10.7	10.0	12.4	25.1	26.1	24.9	27.4
_P+50T-5	50	-5	10.7	11.2	10.6	13.0	27.1	28.1	27.4	28.9
_P-50T-4	-50	-4	8.6	9.1	8.4	10.8	10.9	11.3	10.7	13.1
_P-40T-4	-40	-4	8.8	9.3	8.5	11.0	11.4	11.9	11.2	14.1
_P-30T-4	-30	-4	9.1	9.5	8.8	11.3	12.5	13.2	12.2	15.6
_P-20T-4	-20	-4	9.4	9.9	9.1	11.7	14.1	14.8	13.7	17.8
_P-10T-4	-10	-4	9.8	10.3	9.5	12.2	16.2	17.2	15.8	20.2
P_P+0T-4	0	-4	10.3	10.8	10.0	12.7	18.7	19.7	18.2	22.4
_P+10T-4	10	-4	10.8	11.4	10.6	13.2	21.2	22.3	20.9	24.7
_P+20T-4	20	-4	11.4	11.9	11.2	13.7	24.1	25.1	24.2	26.2
_P+30T-4	30	-4	11.9	12.4	11.8	14.2	26.4	27.4	27.0	27.7
_P+40T-4	40	-4	12.5	13.0	12.3	14.8	28.8	29.1	29.6	28.9
_P+50T-4	50	-4	13.1	13.7	13.0	15.5	30.6	30.9	31.9	29.9
_P-50T-3	-50	-3	9.9	10.4	9.6	12.0	12.4	12.9	12.2	14.8
_P-40T-3	-40	-3	10.2	10.6	9.8	12.3	13.7	14.2	13.4	16.3
_P-30T-3	-30	-3	10.5	11.0	10.2	12.7	15.5	16.2	15.5	18.9
_P-20T-3	-20	-3	11.0	11.5	10.6	13.3	17.8	18.7	17.8	21.1
_P-10T-3	-10	-3	11.6	12.1	11.2	13.9	20.1	20.9	20.1	23.0
P_P+0T-3	0	-3	12.3	12.8	11.9	14.5	22.6	23.5	22.9	25.1
_P+10T-3	10	-3	13.0	13.6	12.8	15.2	25.1	25.9	25.8	26.8
_P+20T-3	20	-3	13.8	14.4	13.6	15.9	27.4	28.3	28.5	28.2
_P+30T-3	30	-3	14.6	15.2	14.5	16.6	29.7	30.1	31.4	29.3
_P+40T-3	40	-3	15.5	16.0	15.4	17.3	31.6	31.8	34.0	30.2
_P+50T-3	50	-3	16.4	16.9	16.4	18.0	33.1	33.0	35.9	31.2

Table 3.6 (Cont'd)

Combination	Δprecip (%)	ΔTemp (C)	DC-na1-AD-yield (t/ha)	DC-na10-AD-yield (t/ha)	DC-na11-AD-yield (t/ha)	DC-spk-AD-yield (t/ha)	DC-na1-FJ-yield (t/ha)	DC-na10-FJ-yield (t/ha)	DC-na11-FJ-yield (t/ha)	DC-spk-FJ-yield (t/ha)
_P-50T-2	-50	-2	11.1	11.7	10.8	12.8	14.1	14.7	13.8	16.2
_P-40T-2	-40	-2	11.4	12.0	11.1	13.2	16.1	16.8	15.7	18.5
_P-30T-2	-30	-2	11.9	12.5	11.6	13.7	18.4	19.4	18.1	20.8
_P-20T-2	-20	-2	12.5	13.1	12.2	14.4	20.9	22.0	20.6	22.9
_P-10T-2	-10	-2	13.3	13.9	13.0	15.3	23.5	24.4	23.4	24.9
P_P+0T-2	0	-2	14.3	14.9	14.0	16.2	26.2	27.0	26.5	26.6
_P+10T-2	10	-2	15.3	15.9	15.2	17.0	28.9	29.2	29.6	28.1
_P+20T-2	20	-2	16.4	17.0	16.4	17.8	31.2	31.2	32.5	29.2
_P+30T-2	30	-2	17.4	17.9	17.5	18.5	33.1	32.8	35.2	30.1
_P+40T-2	40	-2	18.2	18.7	18.7	19.2	34.6	34.2	37.6	31.1
_P+50T-2	50	-2	19.1	19.5	19.7	19.9	36.2	35.5	39.4	32.2
_P-50T-1	-50	-1	12.2	12.6	11.9	13.5	15.4	16.2	15.1	17.2
_P-40T-1	-40	-1	12.5	13.0	12.3	14.0	17.8	18.6	17.4	19.6
_P-30T-1	-30	-1	13.1	13.6	12.8	14.5	20.6	21.4	20.2	22.0
_P-20T-1	-20	-1	13.8	14.2	13.5	15.3	23.4	23.9	23.2	24.1
_P-10T-1	-10	-1	14.7	15.2	14.4	16.2	26.0	26.4	26.4	26.2
P_P+0T-1	0	-1	15.8	16.3	15.7	17.1	28.4	28.8	29.5	27.6
_P+10T-1	10	-1	17.0	17.4	17.0	18.1	30.8	31.0	32.5	28.9
_P+20T-1	20	-1	18.1	18.5	18.3	18.9	33.1	32.7	35.5	30.1
_P+30T-1	30	-1	19.2	19.4	19.6	19.7	34.7	34.2	38.1	30.9
_P+40T-1	40	-1	20.2	20.4	20.9	20.5	36.3	35.7	40.0	31.7
_P+50T-1	50	-1	21.2	21.5	22.1	21.4	37.7	36.7	41.9	32.5
_P-50T+0	-50	0	13.0	13.5	12.8	14.1	16.7	17.4	16.3	18.2
_P-40T+0	-40	0	13.4	13.9	13.2	14.6	19.4	20.1	19.0	20.9
_P-30T+0	-30	0	14.0	14.5	13.7	15.2	22.5	23.3	22.2	23.4
_P-20T+0	-20	0	14.8	15.3	14.5	16.0	25.6	26.1	25.7	25.3
_P-10T+0	-10	0	15.8	16.4	15.6	17.1	28.1	28.6	29.0	27.2
P_P+0T+0	0	0	17.1	17.6	17.0	18.1	30.4	30.9	32.0	28.7
_P+10T+0	10	0	18.4	18.9	18.4	19.0	32.9	32.9	34.9	30.0
_P+20T+0	20	0	19.8	20.1	19.9	19.8	34.6	34.5	37.9	30.9
_P+30T+0	30	0	20.7	21.0	21.4	20.7	36.2	35.8	39.8	31.7
_P+40T+0	40	0	21.7	22.0	22.6	21.6	37.6	36.9	41.6	32.4
_P+50T+0	50	0	22.9	23.1	23.7	22.7	38.7	37.9	43.5	33.3
_P-50T+1	-50	1	13.8	14.2	13.5	14.6	17.7	18.3	17.2	18.9
_P-40T+1	-40	1	14.2	14.6	14.0	15.1	20.6	21.2	20.1	21.6

Table 3.6 (Cont'd)

Combination	Δprecip (%)	ΔTemp (C)	DC-na1-AD-yield (t/ha)	DC-na10-AD-yield (t/ha)	DC-na11-AD-yield (t/ha)	DC-spk-AD-yield (t/ha)	DC-na1-FJ-yield (t/ha)	DC-na10-FJ-yield (t/ha)	DC-na11-FJ-yield (t/ha)	DC-spk-FJ-yield (t/ha)
_P-30T+1	-30	1	14.9	15.2	14.6	15.8	24.1	24.6	23.6	24.0
_P-20T+1	-20	1	15.7	16.1	15.5	16.6	27.0	27.2	27.3	25.9
_P-10T+1	-10	1	16.9	17.2	16.6	17.7	29.3	29.5	30.7	27.5
P_P+0T+1	0	1	18.2	18.5	18.1	18.7	31.6	31.6	33.5	28.9
_P+10T+1	10	1	19.6	19.9	19.6	19.6	34.0	33.4	36.3	29.9
_P+20T+1	20	1	20.8	20.9	21.2	20.5	35.5	34.9	39.0	30.8
_P+30T+1	30	1	21.9	21.9	22.6	21.3	37.1	36.1	40.9	31.6
_P+40T+1	40	1	23.0	23.0	23.8	22.3	38.5	37.2	42.9	32.4
_P+50T+1	50	1	24.2	24.3	25.2	23.2	39.6	38.3	44.9	33.0
_P-50T+2	-50	2	14.4	14.8	14.1	15.1	18.8	19.2	18.2	19.7
_P-40T+2	-40	2	14.9	15.3	14.6	15.6	21.9	22.2	21.2	22.3
_P-30T+2	-30	2	15.6	16.0	15.3	16.3	25.5	25.5	25.0	24.6
_P-20T+2	-20	2	16.5	16.9	16.2	17.2	28.1	28.1	28.7	26.4
_P-10T+2	-10	2	17.8	18.0	17.4	18.2	30.6	30.7	32.0	27.9
P_P+0T+2	0	2	19.1	19.4	18.9	19.2	33.1	32.7	34.8	29.4
_P+10T+2	10	2	20.5	20.6	20.5	20.0	35.1	34.5	37.7	30.5
_P+20T+2	20	2	21.7	21.6	22.0	20.9	36.9	35.9	40.5	31.4
_P+30T+2	30	2	22.8	22.7	23.4	21.8	38.2	37.1	42.4	32.1
_P+40T+2	40	2	24.0	23.8	24.7	22.8	39.5	38.2	44.5	32.7
_P+50T+2	50	2	25.2	25.1	26.2	23.8	40.6	39.0	46.2	33.2
_P-50T+3	-50	3	15.0	15.4	14.7	15.6	19.6	19.8	19.0	20.3
_P-40T+3	-40	3	15.5	15.9	15.2	16.0	22.7	22.8	22.2	22.8
_P-30T+3	-30	3	16.3	16.6	15.9	16.8	26.2	26.0	26.1	25.0
_P-20T+3	-20	3	17.3	17.5	16.8	17.7	28.8	28.5	29.8	27.0
_P-10T+3	-10	3	18.6	18.8	18.1	18.7	31.7	31.2	33.2	28.7
P_P+0T+3	0	3	19.9	20.0	19.6	19.6	34.4	33.6	36.2	30.1
_P+10T+3	10	3	21.3	21.3	21.3	20.4	36.4	35.3	39.4	31.0
_P+20T+3	20	3	22.5	22.3	22.8	21.2	37.9	36.5	41.8	31.8
_P+30T+3	30	3	23.6	23.3	24.2	22.1	39.2	37.5	43.7	32.4
_P+40T+3	40	3	24.8	24.4	25.5	23.1	40.3	38.5	45.6	32.9
_P+50T+3	50	3	26.1	25.7	27.0	23.9	41.3	39.4	47.0	33.1
_P-50T+4	-50	4	15.5	15.9	15.2	16.0	20.5	20.4	19.7	20.9
_P-40T+4	-40	4	16.1	16.4	15.7	16.5	23.8	23.5	23.1	23.6
_P-30T+4	-30	4	16.9	17.1	16.4	17.2	27.5	27.0	27.2	25.6
_P-20T+4	-20	4	17.9	18.1	17.4	18.2	30.4	29.8	30.9	27.7

Table 3.6 (Cont'd)

Combination	Δprecip (%)	ΔTemp (C)	DC-na1-AD-yield (t/ha)	DC-na10-AD-yield (t/ha)	DC-na11-AD-yield (t/ha)	DC-spk-AD-yield (t/ha)	DC-na1-FJ-yield (t/ha)	DC-na10-FJ-yield (t/ha)	DC-na11-FJ-yield (t/ha)	DC-spk-FJ-yield (t/ha)
_P-10T+4	-10	4	19.2	19.4	18.6	19.2	33.3	32.6	34.6	29.3
P_P+0T+4	0	4	20.7	20.7	20.2	20.0	36.0	35.0	37.9	30.4
_P+10T+4	10	4	22.0	21.8	21.8	20.8	38.1	36.7	41.0	31.1
_P+20T+4	20	4	23.1	22.9	23.4	21.7	39.5	37.9	43.4	31.8
_P+30T+4	30	4	24.2	24.0	24.7	22.6	40.8	39.0	45.3	32.3
_P+40T+4	40	4	25.5	25.1	26.1	23.5	41.9	39.9	47.0	32.6
_P+50T+4	50	4	26.9	26.4	27.6	24.5	42.8	40.7	48.2	32.8
_P-50T+5	-50	5	16.0	16.3	15.7	16.4	21.2	21.0	20.3	21.4
_P-40T+5	-40	5	16.7	16.8	16.2	16.9	24.8	24.4	23.8	23.9
_P-30T+5	-30	5	17.4	17.6	16.9	17.6	28.4	27.7	28.0	26.1
_P-20T+5	-20	5	18.5	18.5	17.9	18.5	31.5	30.6	31.9	28.1
_P-10T+5	-10	5	19.9	19.8	19.2	19.5	34.5	33.3	35.6	29.9
P_P+0T+5	0	5	21.3	21.1	20.7	20.3	37.2	35.5	38.9	31.1
_P+10T+5	10	5	22.5	22.2	22.3	21.1	39.0	37.0	42.2	31.9
_P+20T+5	20	5	23.6	23.3	23.8	22.1	40.3	38.0	44.6	32.6
_P+30T+5	30	5	24.8	24.3	25.1	23.0	41.5	39.1	46.4	33.2
_P+40T+5	40	5	26.1	25.5	26.5	23.9	42.6	40.0	47.9	33.5
_P+50T+5	50	5	27.6	26.8	28.1	24.7	43.6	40.8	49.1	33.6

Table 3. 7 Summary data for Sensitivity analysis Mbeya (MB), Tanzania

Combination	Δ precip (%)	Δ Temp (C)	MB-na1-AD-yield (t/ha)	MB-na10-AD-yield (t/ha)	MB-na11-AD-yield (t/ha)	MB-spk-AD-yield (t/ha)	MB-na1-FJ-yield (t/ha)	MB-na10-FJ-yield (t/ha)	MB-na11-FJ-yield (t/ha)	MB-spk-FJ-yield (t/ha)
_P-50T-5	-50	-5	7.8	8.2	7.5	9.8	9.6	10.4	7.5	12.7
_P-40T-5	-40	-5	9.2	9.7	8.8	11.3	11.3	12.2	8.8	15.1
_P-30T-5	-30	-5	10.7	11.2	10.2	12.6	12.9	13.8	10.2	16.8
_P-20T-5	-20	-5	11.8	12.3	11.5	13.5	14.3	15.2	11.5	18.0
_P-10T-5	-10	-5	12.9	13.3	12.5	14.3	15.6	16.7	12.5	19.1
P_P+0T-5	0	-5	13.8	14.2	13.4	14.9	16.7	17.9	13.4	19.9
_P+10T-5	10	-5	14.5	14.9	14.1	15.5	17.8	19.1	14.1	20.7
_P+20T-5	20	-5	15.2	15.5	14.8	15.9	19.0	20.2	14.8	21.3
_P+30T-5	30	-5	15.8	16.1	15.3	16.3	20.1	21.3	15.3	22.0
_P+40T-5	40	-5	16.3	16.5	15.8	16.7	21.1	22.1	15.8	22.6
_P+50T-5	50	-5	16.8	16.9	16.2	17.0	22.0	22.7	16.2	23.0
_P-50T-4	-50	-4	8.3	8.7	8.0	10.4	11.1	12.1	8.0	15.0
_P-40T-4	-40	-4	9.9	10.4	9.5	12.1	13.1	14.4	9.5	17.8
_P-30T-4	-30	-4	11.5	12.0	11.0	13.4	14.9	16.0	11.0	19.6
_P-20T-4	-20	-4	12.7	13.2	12.3	14.4	16.3	17.5	12.3	20.9
_P-10T-4	-10	-4	13.8	14.3	13.5	15.2	17.6	19.0	13.5	21.8
P_P+0T-4	0	-4	14.8	15.2	14.4	15.8	18.8	20.2	14.4	22.4
_P+10T-4	10	-4	15.6	15.9	15.1	16.3	19.9	21.4	15.1	23.1
_P+20T-4	20	-4	16.3	16.5	15.8	16.7	21.3	22.6	15.8	23.8
_P+30T-4	30	-4	17.0	17.1	16.4	17.1	22.5	23.7	16.4	24.7
_P+40T-4	40	-4	17.5	17.5	16.8	17.4	23.6	24.6	16.8	25.4
_P+50T-4	50	-4	18.0	18.0	17.2	17.8	24.4	25.3	17.2	25.7
_P-50T-3	-50	-3	8.9	9.3	8.6	11.1	12.8	14.2	8.6	17.5
_P-40T-3	-40	-3	10.7	11.2	10.2	12.9	15.2	16.5	10.2	20.3
_P-30T-3	-30	-3	12.5	12.9	12.0	14.2	17.1	18.5	12.0	22.5
_P-20T-3	-20	-3	13.8	14.3	13.4	15.2	18.7	20.1	13.4	23.8
_P-10T-3	-10	-3	15.0	15.4	14.7	16.1	20.1	21.7	14.7	24.6
P_P+0T-3	0	-3	16.0	16.3	15.6	16.7	21.2	22.9	15.6	25.3
_P+10T-3	10	-3	16.9	17.0	16.5	17.3	22.5	24.0	16.5	26.2
_P+20T-3	20	-3	17.6	17.7	17.1	17.7	23.9	25.3	17.1	27.0
_P+30T-3	30	-3	18.2	18.2	17.7	18.0	25.4	26.7	17.7	28.1
_P+40T-3	40	-3	18.8	18.6	18.2	18.4	26.5	27.8	18.2	28.8
_P+50T-3	50	-3	19.3	19.1	18.6	18.6	27.7	28.8	18.6	29.2
_P-50T-2	-50	-2	9.6	10.1	9.3	11.9	14.8	16.3	9.3	19.9
_P-40T-2	-40	-2	11.7	12.2	11.2	13.8	17.2	18.7	11.2	22.8
_P-30T-2	-30	-2	13.6	14.0	13.3	15.2	19.4	20.8	13.3	25.0

Table 3.7 (Cont'd)

Combination	Δ precip (%)	Δ Temp (C)	MB-na1-AD-yield (t/ha)	MB-na10-AD-yield (t/ha)	MB-na11-AD-yield (t/ha)	MB-spk-AD-yield (t/ha)	MB-na1-FJ-yield (t/ha)	MB-na10-FJ-yield (t/ha)	MB-na11-FJ-yield (t/ha)	MB-spk-FJ-yield (t/ha)
_P-20T-2	-20	-2	15.1	15.5	14.9	16.2	21.2	22.7	14.9	26.5
_P-10T-2	-10	-2	16.3	16.6	16.3	17.1	22.7	24.4	16.3	27.8
P_P+0T-2	0	-2	17.3	17.6	17.3	17.8	24.0	25.8	17.3	28.7
_P+10T-2	10	-2	18.2	18.2	18.1	18.3	25.7	27.4	18.1	30.1
_P+20T-2	20	-2	18.9	18.9	18.8	18.5	27.3	29.1	18.8	30.8
_P+30T-2	30	-2	19.6	19.5	19.3	18.8	29.3	31.1	19.3	31.4
_P+40T-2	40	-2	20.1	19.8	19.7	19.1	31.0	32.5	19.7	32.1
_P+50T-2	50	-2	20.7	20.3	20.1	19.4	32.7	33.9	20.1	32.2
_P-50T-1	-50	-1	10.5	10.9	10.1	12.6	16.8	18.4	10.1	22.5
_P-40T-1	-40	-1	12.7	13.2	12.4	14.6	19.3	21.0	12.4	25.3
_P-30T-1	-30	-1	14.7	15.1	14.7	16.0	21.6	22.9	14.7	27.5
_P-20T-1	-20	-1	16.3	16.6	16.4	17.0	23.5	25.0	16.4	29.2
_P-10T-1	-10	-1	17.6	17.8	17.8	17.9	25.5	27.2	17.8	30.6
P_P+0T-1	0	-1	18.7	18.8	18.8	18.5	27.1	29.2	18.8	31.8
_P+10T-1	10	-1	19.5	19.5	19.7	19.0	29.3	31.2	19.7	33.1
_P+20T-1	20	-1	20.2	20.1	20.3	19.2	31.4	33.2	20.3	33.5
_P+30T-1	30	-1	20.8	20.5	20.9	19.4	33.9	35.4	20.9	33.4
_P+40T-1	40	-1	21.3	20.9	21.2	19.7	35.8	36.7	21.2	34.1
_P+50T-1	50	-1	21.8	21.3	21.7	20.0	37.9	38.0	21.7	34.1
_P-50T+0	-50	0	11.3	11.7	11.1	13.2	18.9	20.6	11.1	24.8
_P-40T+0	-40	0	13.7	14.2	13.6	15.3	21.5	23.1	13.6	27.7
_P-30T+0	-30	0	15.9	16.2	16.0	16.7	23.7	25.1	16.0	29.9
_P-20T+0	-20	0	17.5	17.7	17.8	17.7	25.9	27.6	17.8	31.5
_P-10T+0	-10	0	18.8	18.8	19.3	18.4	28.4	30.3	19.3	33.2
P_P+0T+0	0	0	19.8	19.8	20.3	19.1	30.6	33.0	20.3	34.3
_P+10T+0	10	0	20.6	20.5	21.1	19.5	33.3	35.2	21.1	35.3
_P+20T+0	20	0	21.2	21.0	21.7	19.6	35.6	37.0	21.7	35.6
_P+30T+0	30	0	21.8	21.3	22.2	19.8	38.4	39.1	22.2	35.7
_P+40T+0	40	0	22.2	21.7	22.6	20.1	40.1	40.0	22.6	35.8
_P+50T+0	50	0	22.6	22.0	23.0	20.4	41.9	41.1	23.0	35.5
_P-50T+1	-50	1	12.6	19.6	20.5	13.9	21.8	33.8	20.5	35.4
_P-40T+1	-40	1	14.7	15.0	14.8	15.8	23.5	25.2	14.8	29.9
_P-30T+1	-30	1	16.8	17.0	17.4	17.1	26.0	27.5	17.4	31.9
_P-20T+1	-20	1	18.4	18.6	19.1	18.2	28.8	30.6	19.1	33.7
_P-10T+1	-10	1	19.6	19.6	20.5	18.9	31.8	33.8	20.5	35.4

Table 3.7 (Cont'd)

Combination	Δ precip (%)	Δ Temp (C)	MB-na1-AD-yield (t/ha)	MB-na10-AD-yield (t/ha)	MB-na11-AD-yield (t/ha)	MB-spk-AD-yield (t/ha)	MB-na1-FJ-yield (t/ha)	MB-na10-FJ-yield (t/ha)	MB-na11-FJ-yield (t/ha)	MB-spk-FJ-yield (t/ha)
P_P+0T+1	0	1	20.6	20.5	21.5	19.6	34.7	36.6	21.5	36.3
_P+10T+1	10	1	21.3	21.2	22.3	19.9	37.8	39.2	22.3	36.9
_P+20T+1	20	1	21.8	21.6	22.9	20.0	40.3	40.8	22.9	36.8
_P+30T+1	30	1	22.3	21.9	23.3	20.2	42.4	42.3	23.3	36.2
_P+40T+1	40	1	22.8	22.2	23.7	20.5	44.0	42.8	23.7	36.2
_P+50T+1	50	1	23.2	22.5	24.1	20.7	45.5	43.5	24.1	35.7
_P-50T+2	-50	2	12.9	13.2	12.9	13.9	22.9	24.7	12.9	27.9
_P-40T+2	-40	2	15.5	15.6	15.9	16.3	25.8	27.6	15.9	31.3
_P-30T+2	-30	2	17.5	17.5	18.4	17.5	28.6	30.4	18.4	33.2
_P-20T+2	-20	2	19.1	19.1	20.1	18.6	32.0	33.8	20.1	35.4
_P-10T+2	-10	2	20.1	20.1	21.4	19.3	35.9	37.2	21.4	36.8
P_P+0T+2	0	2	21.1	21.0	22.4	19.9	38.9	40.0	22.4	37.4
_P+10T+2	10	2	21.9	21.7	23.1	20.3	42.2	42.1	23.1	37.2
_P+20T+2	20	2	22.4	22.1	23.7	20.3	44.0	43.1	23.7	36.9
_P+30T+2	30	2	22.9	22.4	24.1	20.5	45.5	43.7	24.1	36.3
_P+40T+2	40	2	23.4	22.8	24.5	20.8	46.1	44.0	24.5	36.3
_P+50T+2	50	2	23.8	23.1	24.9	21.0	47.3	44.4	24.9	35.7
_P-50T+3	-50	3	13.4	13.7	13.6	14.3	24.8	26.6	13.6	28.7
_P-40T+3	-40	3	16.1	16.1	16.8	16.6	28.1	29.8	16.8	32.5
_P-30T+3	-30	3	18.0	17.9	19.1	17.9	31.7	33.3	19.1	34.2
_P-20T+3	-20	3	19.6	19.6	20.8	19.0	35.5	37.0	20.8	36.5
_P-10T+3	-10	3	20.7	20.6	22.1	19.6	39.6	40.1	22.1	37.6
P_P+0T+3	0	3	21.7	21.6	23.1	20.2	42.5	42.8	23.1	37.9
_P+10T+3	10	3	22.4	22.3	23.8	20.6	45.0	43.8	23.8	37.4
_P+20T+3	20	3	23.0	22.6	24.3	20.6	46.3	44.2	24.3	37.1
_P+30T+3	30	3	23.5	22.9	24.8	20.8	47.1	44.4	24.8	36.5
_P+40T+3	40	3	23.9	23.2	25.1	21.1	47.3	44.5	25.1	36.4
_P+50T+3	50	3	24.3	23.5	25.5	21.4	48.3	44.7	25.5	35.7
_P-50T+4	-50	4	14.0	14.2	14.3	14.7	26.7	28.5	14.3	29.3
_P-40T+4	-40	4	16.6	16.5	17.5	16.9	30.5	32.1	17.5	33.2
_P-30T+4	-30	4	18.4	18.4	19.7	18.1	34.6	35.4	19.7	34.9
_P-20T+4	-20	4	20.1	20.1	21.4	19.2	38.6	39.6	21.4	36.9
_P-10T+4	-10	4	21.2	21.1	22.7	19.8	42.8	42.1	22.7	37.8
P_P+0T+4	0	4	22.2	22.1	23.7	20.5	45.1	44.3	23.7	38.2
_P+10T+4	10	4	23.0	22.7	24.4	20.9	46.9	44.6	24.4	37.4
_P+20T+4	20	4	23.5	23.0	25.0	20.9	47.7	44.7	25.0	37.1

Table 3.7 (Cont'd)

Combination	**Δ precip (%)**	**Δ Temp (C)**	**MB-na1-AD-yield (t/ha)**	**MB-na10-AD-yield (t/ha)**	**MB-na11-AD-yield (t/ha)**	**MB-spk-AD-yield (t/ha)**	**MB-na1-FJ-yield (t/ha)**	**MB-na10-FJ-yield (t/ha)**	**MB-na11-FJ-yield (t/ha)**	**MB-spk-FJ-yield (t/ha)**
_P+30T+4	30	4	24.0	23.3	25.5	21.1	48.2	44.8	25.5	36.5
_P+40T+4	40	4	24.3	23.6	25.8	21.4	48.0	44.7	25.8	36.4
_P+50T+4	50	4	24.7	23.9	26.2	21.7	48.9	44.9	26.2	35.7
_P-50T+5	-50	5	14.5	14.7	15.0	15.1	28.6	30.1	15.0	29.6
_P-40T+5	-40	5	17.0	16.9	18.0	17.2	32.8	34.0	18.0	33.6
_P-30T+5	-30	5	18.8	18.8	20.2	18.4	37.1	37.5	20.2	35.1
_P-20T+5	-20	5	20.6	20.6	22.0	19.5	41.3	41.5	22.0	37.0
_P-10T+5	-10	5	21.7	21.5	23.3	20.1	45.4	43.7	23.3	37.8
P_P+0T+5	0	5	22.7	22.4	24.4	20.8	47.0	45.3	24.4	38.2
_P+10T+5	10	5	23.4	23.1	25.2	21.2	48.0	44.9	25.2	37.4
_P+20T+5	20	5	23.9	23.4	25.7	21.2	48.4	44.9	25.7	37.1
_P+30T+5	30	5	24.4	23.7	26.2	21.4	48.4	44.9	26.2	36.5
_P+40T+5	40	5	24.7	24.0	26.5	21.7	48.1	44.7	26.5	36.4
_P+50T+5	50	5	25.1	24.2	26.9	22.0	49.0	44.9	26.9	35.7

Table 3. 8 Summary data for sensitivity analysis Namulonge (NAM), Uganda

Combination	Δ precip (%)	Δ Temp (C)	NAM-na1-AD-yield (t/ha)	NAM-na10-AD-yield (t/ha)	NAM-na11-AD-yield (t/ha)	NAM-spk-AD-yield (t/ha)	NAM-na1-FJ-yield (t/ha)	NAM-na10-FJ-yield (t/ha)	NAM-na11-FJ-yield (t/ha)	NAM-spk-FJ-yield (t/ha)
_P-50T-5	-50	-5	11.5	12.2	12.0	13.7	11.5	12.7	12.0	13.2
_P-40T-5	-40	-5	12.5	13.1	12.1	15.4	12.5	13.7	13.1	15.5
_P-30T-5	-30	-5	14.0	14.8	13.6	16.7	13.2	15.1	14.2	16.5
_P-20T-5	-20	-5	15.3	16.2	14.9	17.8	14.5	16.2	15.2	17.2
_P-10T-5	-10	-5	16.6	17.5	16.1	18.8	15.5	17.2	16.1	18.1
P_P+0T-5	0	-5	17.7	18.6	17.1	19.7	16.6	18.1	16.9	18.7
_P+10T-5	10	-5	18.8	19.6	18.0	20.4	17.4	18.7	17.6	19.3
_P+20T-5	20	-5	19.8	20.4	18.9	21.1	18.2	19.3	18.4	19.9
_P+30T-5	30	-5	20.6	21.1	19.7	21.7	18.9	19.9	19.0	20.3
_P+40T-5	40	-5	21.4	21.5	20.5	22.2	19.6	20.3	19.7	20.7
_P+50T-5	50	-5	22.1	22.1	21.1	22.6	20.0	20.8	20.2	21.1
_P-50T-4	-50	-4	12.1	13.0	11.5	16.1	20.5	13.2	12.5	15.5
_P-40T-4	-40	-4	14.1	14.9	13.5	17.8	12.7	14.7	13.9	16.8
_P-30T-4	-30	-4	15.9	16.8	15.4	19.3	14.1	16.2	15.2	17.9
_P-20T-4	-20	-4	17.4	18.5	16.9	20.4	15.5	17.4	16.3	18.7
_P-10T-4	-10	-4	19.0	20.1	18.4	21.7	16.6	18.7	17.4	19.7
P_P+0T-4	0	-4	20.3	21.4	19.5	22.6	17.9	19.7	18.3	20.5
_P+10T-4	10	-4	21.6	22.5	20.6	23.4	19.0	20.4	19.2	21.2
_P+20T-4	20	-4	22.8	23.3	21.6	24.0	19.9	21.1	20.1	21.9
_P+30T-4	30	-4	23.8	24.1	22.5	24.6	20.8	21.8	20.8	22.3
_P+40T-4	40	-4	24.8	24.6	23.3	25.3	21.5	22.3	21.5	22.7
_P+50T-4	50	-4	25.5	25.2	24.0	25.7	22.0	22.7	22.0	23.2
_P-50T-3	-50	-3	14.0	15.2	13.4	18.9	12.5	14.4	13.5	17.1
_P-40T-3	-40	-3	16.6	17.7	15.9	21.0	13.8	16.1	15.0	18.6
_P-30T-3	-30	-3	18.6	19.8	18.2	22.4	15.3	17.9	16.6	19.9
_P-20T-3	-20	-3	20.3	21.5	19.9	23.4	17.0	19.2	17.9	20.8
_P-10T-3	-10	-3	22.2	23.4	21.7	24.8	18.3	20.7	19.2	22.0
P_P+0T-3	0	-3	23.7	24.9	23.1	25.6	19.9	22.0	20.4	23.0
_P+10T-3	10	-3	25.2	26.0	24.4	26.3	21.2	22.9	21.5	23.7
_P+20T-3	20	-3	26.4	26.9	25.5	26.9	22.6	23.9	22.6	24.6
_P+30T-3	30	-3	27.4	27.7	26.5	27.1	23.6	24.6	23.4	25.2
_P+40T-3	40	-3	28.8	28.4	27.4	28.1	24.5	25.2	24.2	25.4
_P+50T-3	50	-3	28.8	29.4	28.3	28.9	25.1	26.5	24.9	26.8
_P-50T-2	-50	-2	16.6	18.0	15.9	22.1	26.2	16.0	14.8	19.4
_P-40T-2	-40	-2	19.4	20.8	18.7	24.2	15.2	18.0	16.7	21.1

Table 3.8 (Cont'd)

Combination	Δ precip (%)	Δ Temp (C)	NAM-na1-AD-yield (t/ha)	NAM-na10-AD-yield (t/ha)	NAM-na11-AD-yield (t/ha)	NAM-spk-AD-yield (t/ha)	NAM-na1-FJ-yield (t/ha)	NAM-na10-FJ-yield (t/ha)	NAM-na11-FJ-yield (t/ha)	NAM-spk-FJ-yield (t/ha)
_P-30T-2	-30	-2	21.6	23.1	21.3	25.8	17.1	20.1	18.6	22.6
_P-20T-2	-20	-2	23.6	24.9	23.3	26.7	19.1	21.7	20.2	23.6
_P-10T-2	-10	-2	25.8	27.0	25.4	27.6	20.8	23.5	21.8	24.9
P_P+0T-2	0	-2	27.2	28.3	26.9	28.3	22.7	25.3	23.3	26.1
_P+10T-2	10	-2	28.8	29.4	28.3	28.9	24.4	26.5	24.9	26.8
_P+20T-2	20	-2	30.1	30.6	29.6	29.7	26.2	27.4	26.3	27.7
_P+30T-2	30	-2	31.1	31.1	30.7	29.6	27.5	28.3	27.2	28.2
_P+40T-2	40	-2	32.9	32.3	31.9	30.7	28.8	28.9	28.2	28.4
_P+50T-2	50	-2	33.6	32.7	32.6	30.7	29.4	29.4	28.9	28.6
_P-50T-1	-50	-1	19.2	20.9	18.6	24.9	16.1	18.5	16.8	22.2
_P-40T-1	-40	-1	22.4	24.0	21.8	27.4	17.3	20.9	19.2	23.9
_P-30T-1	-30	-1	25.1	26.6	24.8	29.0	19.7	23.2	21.4	25.8
_P-20T-1	-20	-1	27.1	28.5	27.1	29.7	22.0	25.1	23.5	27.4
_P-10T-1	-10	-1	29.3	30.4	29.5	30.3	24.1	27.5	25.6	28.6
P_P+0T-1	0	-1	30.9	31.9	31.3	31.4	26.7	29.6	27.6	29.6
_P+10T-1	10	-1	32.6	33.1	32.9	31.5	28.9	30.5	29.6	30.2
_P+20T-1	20	-1	34.2	34.6	34.6	32.1	30.6	31.7	31.1	30.5
_P+30T-1	30	-1	35.4	35.2	35.5	31.7	32.6	32.8	32.4	31.0
_P+40T-1	40	-1	37.4	36.4	37.3	32.6	33.8	33.4	33.5	31.4
_P+50T-1	50	-1	38.1	36.5	38.2	32.4	34.7	33.9	34.8	30.7
_P-50T+0	-50	0	22.6	24.3	21.7	27.9	18.5	21.4	19.6	25.0
_P-40T+0	-40	0	25.8	27.5	25.4	30.3	20.2	24.0	22.5	27.3
_P-30T+0	-30	0	28.9	30.4	29.0	31.6	22.8	27.0	25.6	29.4
_P-20T+0	-20	0	31.0	32.5	31.5	32.4	25.8	29.8	28.3	30.9
_P-10T+0	-10	0	33.3	34.2	34.1	32.7	28.7	32.4	31.1	32.2
P_P+0T+0	0	0	35.2	36.0	36.1	33.6	31.9	33.9	33.7	32.7
_P+10T+0	10	0	36.7	36.3	37.8	33.6	34.2	34.6	35.9	32.9
_P+20T+0	20	0	38.5	37.8	39.8	34.1	35.7	35.9	37.9	32.7
_P+30T+0	30	0	39.2	37.7	40.9	33.3	37.4	37.1	39.3	33.1
_P+40T+0	40	0	40.9	39.2	42.9	33.9	39.1	37.8	41.1	32.7
_P+50T+0	50	0	41.8	39.3	43.7	33.6	40.4	37.8	41.8	31.5
_P-50T+1	-50	1	26.3	28.0	25.6	30.1	21.0	24.8	22.8	27.8
_P-40T+1	-40	1	29.8	31.4	29.5	32.1	23.5	27.9	26.7	30.7

Table 3.8 (Cont'd)

Combination	Δ precip (%)	Δ Temp (C)	NAM-na1-AD-yield (t/ha)	NAM-na10-AD-yield (t/ha)	NAM-na11-AD-yield (t/ha)	NAM-spk-AD-yield (t/ha)	NAM-na1-FJ-yield (t/ha)	NAM-na10-FJ-yield (t/ha)	NAM-na11-FJ-yield (t/ha)	NAM-spk-FJ-yield (t/ha)
_P-30T+1	-30	1	33.0	34.4	33.5	33.6	26.9	31.8	30.8	32.9
_P-20T+1	-20	1	35.3	36.4	36.8	34.4	31.1	34.5	34.4	33.8
_P-10T+1	-10	1	37.2	37.2	39.2	34.7	34.1	37.2	38.1	34.6
P_P+0T+1	0	1	39.0	39.1	41.2	35.2	37.3	37.9	40.6	34.8
_P+10T+1	10	1	40.2	39.2	43.0	35.1	39.0	38.9	42.7	34.3
_P+20T+1	20	1	41.4	40.5	44.8	35.4	40.3	39.9	44.5	33.9
_P+30T+1	30	1	42.0	40.4	45.5	34.2	42.0	40.3	45.9	33.9
_P+40T+1	40	1	44.0	42.0	47.1	34.6	43.5	40.3	47.4	33.2
_P+50T+1	50	1	44.8	42.1	48.0	34.2	44.1	39.6	47.8	31.9
_P-50T+2	-50	2	29.8	31.2	29.4	32.0	26.8	28.1	26.7	30.7
_P-40T+2	-40	2	33.7	34.4	34.1	34.0	27.1	32.3	32.0	33.4
_P-30T+2	-30	2	36.8	37.1	38.1	34.9	31.5	36.2	36.8	35.1
_P-20T+2	-20	2	38.6	38.9	41.3	35.8	35.7	39.0	41.2	35.5
_P-10T+2	-10	2	40.0	39.8	43.4	35.6	39.5	40.2	44.4	36.0
P_P+0T+2	0	2	41.9	41.8	45.5	36.2	41.3	40.8	46.8	35.2
_P+10T+2	10	2	42.9	41.7	46.9	35.7	42.6	41.2	48.5	34.6
_P+20T+2	20	2	44.2	43.0	48.7	35.7	43.0	42.2	50.4	34.3
_P+30T+2	30	2	44.6	42.4	49.4	34.4	44.6	41.9	51.3	34.2
_P+40T+2	40	2	46.4	43.9	51.1	34.9	45.6	41.6	52.2	33.5
_P+50T+2	50	2	47.2	43.9	52.3	34.4	45.8	40.4	51.7	32.2
_P-50T+3	-50	3	34.1	35.4	55.8	34.4	32.1	40.8	54.3	32.2
_P-40T+3	-40	3	36.7	37.1	37.8	35.3	34.0	36.0	37.0	35.8
_P-30T+3	-30	3	39.2	39.2	41.8	35.6	35.9	39.8	42.6	36.2
_P-20T+3	-20	3	41.3	41.3	44.6	36.3	39.9	41.6	46.8	36.4
_P-10T+3	-10	3	42.9	42.2	46.7	35.9	42.8	42.2	49.2	36.3
P_P+0T+3	0	3	44.6	43.7	49.2	36.4	43.7	42.3	51.1	35.4
_P+10T+3	10	3	45.4	43.6	50.7	35.9	44.5	42.4	51.9	34.7
_P+20T+3	20	3	46.4	44.1	52.9	35.7	44.4	43.2	53.2	34.4
_P+30T+3	30	3	46.3	43.1	53.2	34.4	46.2	42.7	53.9	34.5
_P+40T+3	40	3	47.6	44.5	55.1	35.0	46.9	42.1	54.6	33.5
_P+50T+3	50	3	48.1	44.4	55.8	34.4	47.0	40.8	54.3	32.2
_P-50T+4	-50	4	36.5	36.9	36.8	33.8	46.0	36.7	36.0	35.1
_P-40T+4	-40	4	39.5	39.3	41.2	35.8	36.0	40.2	42.3	36.7
_P-30T+4	-30	4	41.5	41.3	44.7	36.0	39.9	42.4	47.1	37.2
_P-20T+4	-20	4	43.9	43.5	48.0	36.5	43.0	43.4	50.7	36.8

Table 3.8 (Cont'd)

Combination	**Δ precip (%)**	**Δ Temp (C)**	**NAM-na1-AD-yield (t/ha)**	**NAM-na10-AD-yield (t/ha)**	**NAM-na11-AD-yield (t/ha)**	**NAM-spk-AD-yield (t/ha)**	**NAM-na1-FJ-yield (t/ha)**	**NAM-na10-FJ-yield (t/ha)**	**NAM-na11-FJ-yield (t/ha)**	**NAM-spk-FJ-yield (t/ha)**
_P-10T+4	-10	4	45.2	43.7	50.2	36.0	45.1	42.9	52.8	36.5
P_P+0T+4	0	4	46.7	44.6	52.8	36.5	45.3	42.8	53.9	35.6
_P+10T+4	10	4	47.0	44.2	54.3	36.0	45.6	43.0	54.3	34.9
_P+20T+4	20	4	47.4	44.5	56.0	35.7	45.4	43.6	55.8	34.6
_P+30T+4	30	4	46.8	43.5	56.0	34.5	46.7	43.2	56.3	34.7
_P+40T+4	40	4	48.1	44.8	57.5	35.0	47.5	42.4	56.7	33.6
_P+50T+4	50	4	48.7	44.7	58.2	34.5	47.6	40.9	56.0	32.3
_P-50T+5	-50	5	38.8	38.8	39.8	34.1	38.4	39.2	41.8	36.0
_P-40T+5	-40	5	42.1	41.2	44.1	35.9	40.5	42.3	47.4	37.0
_P-30T+5	-30	5	43.9	42.9	47.6	36.2	43.5	43.8	50.8	37.3
_P-20T+5	-20	5	46.3	44.7	51.5	36.5	45.3	44.0	53.2	37.0
_P-10T+5	-10	5	46.6	44.2	53.7	36.0	46.3	43.3	54.8	36.6
P_P+0T+5	0	5	47.4	45.0	55.8	36.5	45.9	43.0	55.6	35.7
_P+10T+5	10	5	47.6	44.4	56.8	36.0	45.9	43.2	55.8	35.0
_P+20T+5	20	5	47.8	44.7	57.9	35.8	45.8	43.8	57.1	34.7
_P+30T+5	30	5	47.1	43.6	57.2	34.5	47.1	43.4	57.6	34.7
_P+40T+5	40	5	48.4	44.9	58.6	35.0	48.0	42.4	57.7	33.6
_P+50T+5	50	5	48.9	44.9	59.2	34.5	47.9	41.1	56.6	32.3

APPENDIX B: Mean changes in sweet potato yield

Table 3. 9 Ensemble mean changes in sweet potato root yield (t/ha) under future climate scenarios for 4 GCMs; CSIRO, MIROC5, MRI-CGCM3, NorESM1-M for August-December (ASOND) season for NASPOT1: Base yield, 2030- rcp4.5, 2050-rcp4.5, 2070-rcp4.5, 2030-rcp8.5, 2050-rcp8.5, 2070-rcp8.5

Location	**Base root yield - na1-ASOND**	**Change in root yield (mm)**					
		na1-av-ASOND-2030-rcp45	**na1-av-ASOND-2050-rcp45**	**na1-av-ASOND-2070-rcp45**	**na1-av-ASOND-2030-rcp85**	**na1-av-ASOND-2050-rcp85**	**na1-av-ASOND-2050-rcp85**
Arua	47.9	-3.9	-4.6	-5.0	-6.1	-6.1	-4.1
Arusha	6.5	14.1	13.5	13.1	14.5	13.8	13.8
Bukoba	37.8	-2.3	-1.5	-0.6	-0.4	-1.9	0.0
Dagoretti_Corner	17.0	3.8	2.7	2.0	3.4	1.6	1.5
Dar es Salaam	29.4	0.7	0.0	-0.4	0.9	-1.2	0.4
Dodoma	18.7	1.8	1.5	1.1	1.2	1.2	1.1
Eldoret	15.7	1.1	3.0	5.1	1.7	3.4	5.0
Entebbe	28.3	3.8	4.4	6.5	4.9	5.6	7.0
Garissa	22.6	4.1	3.3	3.5	3.1	2.8	2.3
Gulu	35.6	6.9	7.4	7.9	7.4	7.0	7.3
Jinja	28.3	7.5	6.9	6.5	8.5	8.3	7.3
Kabale	21.3	-1.9	-1.4	-1.2	-2.7	-2.9	-2.1
Kasese	37.3	-1.6	-0.8	-0.3	-0.4	-1.7	0.0
Kigoma	29.6	0.7	1.2	-0.4	0.5	0.4	-1.0
Kisumu	30.8	4.7	6.0	6.2	5.7	6.4	6.9
Kitgum	35.9	3.6	4.6	5.2	4.0	4.4	5.5
Lamu	21.0	5.9	6.4	6.3	5.0	4.8	4.8
Lodwar	19.3	0.0	0.9	1.1	3.2	3.4	3.4
Makindu	28.3	-0.2	-0.6	-0.8	-1.6	-1.5	-2.0
Mandera	23.1	1.8	1.3	2.0	1.7	1.5	2.1
Marsabit	24.3	1.6	-1.3	-2.9	2.0	-0.8	-1.9
Masaka	28.5	1.3	2.2	2.5	2.3	3.0	2.8
Masindi	41.0	-4.1	-2.5	-0.7	-1.9	-2.5	-1.4
Mbarara	33.2	-1.7	-3.2	-3.4	-1.2	-3.4	-2.8
Mbeya	20.6	-1.2	-2.0	-2.1	-1.4	-1.3	-2.0
Mtwara	22.1	3.7	3.1	3.0	2.2	2.4	2.8
Musoma	24.5	4.0	3.2	3.3	4.6	4.2	3.7
Mwanza	30.9	0.0	1.1	0.7	0.9	0.8	0.4
Namulonge	36.9	-1.7	-1.4	-0.8	-0.6	-1.9	-1.2
Narok	11.4	4.6	3.5	2.7	5.3	4.2	3.1
Same	16.4	4.2	3.9	3.4	3.3	3.0	2.3

Table 3.9 (Cont'd)

Location	**Base root yield - na1-ASOND**	**Change in root yield (mm)**					
		na1-av-ASOND-2030-rcp45	**na1-av-ASOND-2050-rcp45**	**na1-av-ASOND-2070-rcp45**	**na1-av-ASOND-2030-rcp85**	**na1-av-ASOND-2050-rcp85**	**na1-av-ASOND-2050-rcp85**
Serere	33.3	1.6	3.3	5.2	1.3	4.1	6.2
Songea	20.4	0.6	1.2	0.7	2.0	2.3	1.1
Soroti	35.1	-0.1	1.9	4.5	2.8	4.5	5.5
Tabora	25.6	0.9	0.8	0.7	2.6	2.4	1.4
Tororo	41.6	-6.3	-4.4	-2.8	-5.8	-3.8	-2.4
Voi	26.3	0.9	0.9	0.4	-0.2	0.1	-0.2
Wajir	23.2	5.2	4.8	4.9	5.4	3.6	4.8

Table 3. 10 Ensemble mean changes in sweet potato root yield (t/ha) under future climate scenarios for 4 GCMs; CSIRO, MIROC5, MRI-CGCM3, NorESM1-M for August-December (ASOND) season for NASPOT11

Location	**Base root yield - na11-ASOND**	**Change in root yield (mm)**					
		na11-av-ASOND-2030-rcp45	**na11-av-ASOND-2050-rcp45**	**na11-av-ASOND-2070-rcp45**	**na11-av-ASOND-2030-rcp85**	**na11-av-ASOND-2050-rcp85**	**na11-av-ASOND-2070-rcp85**
Arua	58.3	-4.2	-5.3	-5.7	-6.7	-7.2	-4.2
Arusha	6.2	14.9	14.0	13.3	15.4	14.3	14.5
Bukoba	42.0	-1.7	-0.4	0.8	1.0	-1.0	1.3
Dagoretti_ Corner	17.0	4.9	3.4	2.6	4.4	2.3	2.2
Dar es Salaam	31.5	2.5	1.5	1.1	2.3	0.2	1.5
Dodoma	18.7	1.8	1.3	0.8	1.3	1.2	1.0
Eldoret	14.8	1.7	3.5	5.3	1.9	3.6	5.4
Entebbe	29.6	5.5	5.9	8.9	6.7	7.3	9.9
Garissa	21.8	5.4	4.2	4.6	4.2	3.5	3.0
Gulu	44.5	4.8	5.8	6.3	5.9	6.2	6.4
Jinja	28.7	10.0	9.8	9.0	11.9	11.2	10.3
Kabale	20.5	-0.8	-0.9	-0.7	-2.0	-2.4	-1.5
Kasese	37.1	-0.4	0.8	2.1	2.1	0.1	2.4
Kigoma	30.7	2.2	2.3	0.4	2.2	1.9	-0.2
Kisumu	31.1	8.0	8.9	9.1	9.2	9.3	10.2
Kitgum	34.8	7.2	9.3	10.5	9.1	10.3	12.5
Lamu	21.0	7.6	9.2	9.3	6.6	7.0	7.2
Lodwar	19.1	-0.2	0.7	1.0	3.0	3.2	3.2

Table 3.10 (Cont'd)

Location	Base root yield - na11-ASOND	Change in root yield (mm)					
		na11-av-ASOND-2030-rcp45	na11-av-ASOND-2050-rcp45	na11-av-ASOND-2070-rcp45	na11-av-ASOND-2030-rcp85	na11-av-ASOND-2050-rcp85	na11-av-ASOND-2070-rcp85
Makindu	30.6	0.3	-0.1	-0.4	-1.7	-1.8	-2.4
Mandera	22.4	1.8	1.1	2.2	2.1	1.6	2.4
Marsabit	24.7	2.7	-1.1	-2.8	3.2	-0.5	-1.9
Masaka	29.4	2.1	2.7	3.4	3.7	4.0	4.1
Masindi	36.1	3.7	6.6	9.7	7.0	7.2	8.8
Mbarara	33.3	-0.5	-2.8	-2.2	0.4	-2.6	-2.0
Mbeya	21.4	-1.0	-1.8	-1.9	-1.3	-1.3	-2.2
Mtwara	22.5	4.9	4.3	3.6	2.9	3.2	3.1
Musoma	24.2	5.9	4.9	4.7	7.3	7.0	6.1
Mwanza	34.2	0.0	0.8	0.5	1.5	0.8	0.3
Namulonge	31.0	7.9	7.6	8.5	8.7	6.5	8.0
Narok	10.9	5.3	3.8	2.9	6.3	4.7	3.4
Same	15.9	4.7	4.4	3.9	3.6	3.3	2.7
Serere	32.8	4.5	6.2	9.0	4.6	8.2	12.2
Songea	21.2	1.1	1.6	1.2	2.8	2.6	1.5
Soroti	35.4	2.1	4.9	8.0	5.1	7.6	9.7
Tabora	26.6	2.1	1.6	1.3	4.3	3.3	2.0
Tororo	45.4	-6.8	-4.8	-2.2	-5.8	-2.9	-1.2
Voi	28.7	0.5	-0.1	-0.8	-1.0	-1.2	-1.3
Wajir	22.6	7.1	6.3	5.9	6.7	4.9	5.6

Table 3. 11 Ensemble mean changes in sweet potato root yield (t/ha) under future climate scenarios for 4 GCMs; CSIRO, MIROC5, MRI-CGCM3, NorESM1-M for August-December (ASOND) season for NASPOT10

Location	Base root yield - na10-ASOND	Change in root yield (mm)					
		na10-av-ASOND-2030-rcp45	na10-av-ASOND-2050-rcp45	na10-av-ASOND-2070-rcp45	na10-av-ASOND-2030-rcp85	na10-av-ASOND-2050-rcp85	na10-av-ASOND-2070-rcp85
Arua	44.5	-0.5	-1.2	-1.6	-2.6	-2.7	-0.7
Arusha	6.7	13.8	13.3	12.9	14.3	13.6	13.5
Bukoba	38.1	-2.5	-1.7	-0.8	-0.6	-2.2	-0.2
Dagoretti_Corner	17.5	3.4	2.3	1.6	2.9	1.2	1.1
Dar es Salaam	28.4	1.8	1.0	0.6	1.9	-0.2	1.4
Dodoma	19.3	1.2	1.0	0.6	0.7	0.7	0.5
Eldoret	17.6	-0.8	1.1	3.2	-0.2	1.5	3.1
Entebbe	28.8	3.3	3.9	6.0	4.4	5.1	6.5
Garissa	21.9	4.8	4.0	4.2	3.8	3.5	3.0
Gulu	40.1	2.4	2.8	3.3	2.8	2.5	2.8
Jinja	28.3	7.5	6.9	6.5	8.5	8.3	7.3
Kabale	22.5	-3.1	-2.7	-2.5	-3.9	-4.2	-3.4
Kasese	28.9	6.8	7.5	8.0	8.0	6.7	8.3
Kigoma	29.1	1.2	1.7	0.1	1.0	0.9	-0.5
Kisumu	31.6	4.0	5.2	5.4	4.9	5.7	6.2
Kitgum	35.9	3.7	4.6	5.2	4.1	4.5	5.5
Lamu	21.0	5.9	6.4	6.3	5.0	4.9	4.8
Lodwar	19.3	0.0	0.9	1.1	3.2	3.4	3.4
Makindu	27.3	0.8	0.4	0.1	-0.7	-0.6	-1.0
Mandera	22.3	2.6	2.1	2.8	2.5	2.2	2.8
Marsabit	23.9	2.1	-0.8	-2.4	2.4	-0.3	-1.4
Masaka	28.9	0.9	1.7	2.0	1.9	2.5	2.3
Masindi	36.2	0.8	2.3	4.1	2.9	2.3	3.4
Mbarara	34.1	-2.6	-4.2	-4.4	-2.1	-4.4	-3.8
Mbeya	20.7	-1.3	-2.1	-2.2	-1.5	-1.4	-2.1
Mtwara	22.0	3.9	3.2	3.2	2.4	2.5	2.9
Musoma	24.6	3.9	3.1	3.1	4.5	4.1	3.5
Mwanza	30.6	0.3	1.5	1.0	1.3	1.1	0.7
Namulonge	31.6	3.6	3.9	4.4	4.7	3.4	4.1
Narok	12.0	4.0	3.0	2.1	4.7	3.6	2.5
Same	16.7	3.8	3.6	3.1	2.9	2.7	2.0
Serere	34.0	0.8	2.6	4.4	0.5	3.4	5.4
Songea	20.3	0.7	1.3	0.8	2.1	2.4	1.2
Soroti	35.0	0.0	2.0	4.6	2.9	4.6	5.5

Table 3.11 (Cont'd)

Location	Base root yield - na10-ASOND	Change in root yield (mm)					
		na10-av-ASOND-2030-rcp45	na10-av-ASOND-2050-rcp45	na10-av-ASOND-2070-rcp45	na10-av-ASOND-2030-rcp85	na10-av-ASOND-2050-rcp85	na10-av-ASOND-2070-rcp85
Tabora	25.0	1.5	1.4	1.2	3.2	3.0	2.0
Tororo	41.3	-6.0	-4.1	-2.5	-5.5	-3.5	-2.1
Voi	26.3	0.9	0.9	0.4	-0.2	0.1	-0.2
Wajir	22.3	6.1	5.7	5.8	6.4	4.6	5.7

Table 3. 12 Ensemble mean changes in sweet potato root yield under future climate scenarios for 4 GCMs; CSIRO, MIROC5, MRI-CGCM3, NorESM1-M for August-December (ASOND) season for SPK004

Location	Base root yield - spk-ASOND	Change in root yield (t/ha)					
		spk-av-ASOND-2030-rcp45	spk-av-ASOND-2050-rcp45	spk-av-ASOND-2070-rcp45	spk-av-ASOND-2030-rcp85	spk-av-ASOND-2050-rcp85	spk-av-ASOND-2070-rcp85
Arua	36.1	-2.9	-3.4	-3.7	-4.1	-4.0	-2.5
Arusha	7.9	13.4	13.4	13.1	13.7	13.3	13.2
Bukoba	34.8	-4.4	-4.9	-4.0	-2.7	-4.5	-3.1
Dagoretti_Corner	18.0	2.5	1.8	1.5	2.6	1.3	1.1
Dar es Salaam	25.6	0.3	-0.7	-0.8	0.7	-1.3	0.0
Dodoma	19.1	1.3	1.4	1.0	1.0	1.2	1.0
Eldoret	20.5	0.8	2.6	3.4	-4.2	-2.5	3.5
Entebbe	28.3	0.0	0.7	1.7	1.8	2.7	3.6
Garissa	21.0	2.6	2.4	2.4	2.6	2.4	1.9
Gulu	34.5	-1.4	-1.4	-1.2	-0.3	-0.2	-0.3
Jinja	28.8	2.1	1.8	1.5	4.3	4.1	3.2
Kabale	26.2	-4.5	-3.5	-3.3	-4.5	-4.9	-3.8
Kasese	33.7	-2.2	-1.9	-1.8	0.8	0.1	1.5
Kigoma	27.5	-0.8	-0.4	-1.8	-0.6	-0.7	-1.8
Kisumu	30.3	-0.4	0.5	0.6	1.6	2.4	2.4
Kitgum	32.7	0.0	-0.3	-0.1	1.0	1.4	1.9
Lamu	21.4	2.7	2.1	1.6	2.9	1.9	1.6
Lodwar	19.2	0.0	0.8	1.0	2.9	2.6	2.8
Makindu	24.6	0.0	-0.1	-0.2	-1.0	-0.7	-1.0
Mandera	21.7	0.7	0.7	0.8	1.6	1.5	1.9
Marsabit	22.7	1.0	-0.5	-1.8	1.9	-0.3	-0.9
Masaka	28.6	-1.2	-0.6	-0.2	0.3	0.7	0.2

Table 3.12 (Cont'd)

Location	**Base root yield - spk-ASOND**	**Change in root yield (t/ha)**					
		spk-av-ASOND-2030-rcp45	**spk-av-ASOND-2050-rcp45**	**spk-av-ASOND-2070-rcp45**	**spk-av-ASOND-2030-rcp85**	**spk-av-ASOND-2050-rcp85**	**spk-av-ASOND-2070-rcp85**
Masindi	33.6	-1.9	-1.5	-1.1	0.0	-0.7	-0.3
Mbarara	32.5	-2.3	-2.8	-3.6	-1.6	-3.3	-3.3
Mbeya	18.8	-0.1	-0.6	-0.7	-0.4	-0.3	-0.8
Mtwara	20.9	2.2	1.8	1.9	1.7	1.6	2.1
Musoma	24.2	1.8	1.1	1.7	2.2	2.0	1.8
Mwanza	28.1	-1.0	0.3	-0.3	0.1	0.2	-0.3
Namulonge	31.0	-0.5	0.2	0.2	2.1	1.4	1.6
Narok	13.7	3.7	3.4	2.4	4.4	3.7	2.9
Same	16.9	3.3	3.3	2.8	2.7	2.5	1.8
Serere	31.9	-0.7	-0.3	-0.2	-1.0	0.7	1.8
Songea	19.3	0.2	1.3	0.6	1.6	2.2	1.3
Soroti	32.4	-1.8	-1.0	-0.1	0.8	1.7	2.0
Tabora	23.2	0.1	0.5	0.3	1.4	1.9	1.3
Tororo	35.5	-4.6	-3.5	-3.5	-4.8	-3.7	-2.7
Voi	24.1	0.5	1.4	1.3	-0.2	0.6	0.3
Wajir	21.3	2.7	2.8	3.0	3.9	2.6	4.0

APPENDIX C: Projected changes (%) for annual rainfall

Table 3. 13 Changes in annual rainfall for the 2030s

Location	Base line Annual rainfall (mm)	Change in rainfall (mm)								
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85	Av. RFan-2030s
Arua	1285	6	7	8	7	3	3	20	11	8
Arusha	1058	3	6	-2	2	2	2	3	1	2
Bukoba	2082	-5	-4	-2	0	-4	-3	4	3	-1
Dagoretti Corner	892	15	14	9	10	6	10	9	8	10
Dar es Salaam	1112	-3	0	2	4	-1	1	-13	-8	-2
Dodoma	603	-2	2	-4	2	9	2	5	9	3
Eldoret	1091	-5	-2	-4	-2	-9	-10	-1	3	-4
Entebbe	1354	11	12	16	16	8	9	25	22	15
Garissa	348	20	35	38	32	81	53	23	23	38
Gulu	1379	5	6	9	9	7	7	24	18	11
Jinja	1370	-9	-7	-2	2	-12	-11	0	0	-5
Kabale	1232	-27	-25	-18	-14	-23	-23	-16	-19	-21
Kasese	968	-11	-7	-7	-2	-17	-13	5	-4	-7
Kigoma	1049	-5	-6	-4	0	-11	-4	-1	-4	-4
Kisumu	1494	-12	-14	-10	-7	-26	-25	-11	-8	-14
Kitigum	1117	3	8	12	13	6	5	22	20	11
Lamu	872	-1	5	11	13	5	-2	10	-4	5
Lodwar	200	25	15	-12	18	5	60	43	80	29
Makindu	637	-3	-4	12	4	-1	-8	-6	-13	-3
Mandera	257	-5	4	12	18	36	3	18	52	17
Marsabiti	614	47	48	45	44	41	47	45	46	45
Masaka	1214	-11	-5	-2	-3	-7	-7	5	4	-3
Mansindi	1215	0	3	9	6	-2	2	25	19	8
Mbarara	990	-16	-13	-9	-9	-14	-13	3	-5	-9
Mbeya	1062	-6	-12	-1	-8	-14	-12	0	-3	-7
Mtwara	1049	-7	0	-3	-7	9	0	-14	-9	-4
Musoma	992	-5	-12	-1	4	-11	-8	2	4	-3
Mwanza	1011	2	2	3	9	1	-2	11	10	5

Table 3.13 (Cont'd)

Location	Base line Annual rainfall (mm)	Change in rainfall (mm)								
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85	Av. RFan-2030s
Namulonge	1259	-8	-9	2	1	-7	-6	10	10	-1
Narok	751	12	14	0	15	10	18	12	12	12
Same	554	23	17	15	24	28	20	13	10	19
Serere	1294	-1	1	6	5	-1	-6	9	11	3
Songea	1088	19	17	14	3	12	15	16	27	15
Soroti	1249	6	8	11	8	0	4	13	13	8
Tabora	976	-13	-10	-5	-1	-10	-2	1	0	-5
Tororo	1616	-16	-11	-8	-9	-21	-22	-9	-6	-13
Voi	620	-7	-4	1	0	6	9	1	-17	-2
Wajir	312	19	35	34	16	86	39	20	23	34

Table 3. 14 Changes in annual rainfall (mm) for the 2050s

Location	Baseline Annual rainfall (mm)	Change in rainfall (mm)								
		2040-2069-CSIRO_rcp45	2040-2069-CSIRO_rcp85	2040-2069-MIROC_rcp45	2040-2069-MIROC_rcp85	2040-2069-MRI-CGCM3_rcp45	2040-2069-MRI-CGCM3_rcp85	2040-2069-NorESM1-M_rcp45	2040-2069-NorESM1-M_rcp85	Av. RFan-2050s
Arua	1285	5	5	9	7	5	0	21	8	7
Arusha	1058	4	7	0	3	1	4	4	0	3
Bukoba	2082	-5	-5	-4	-2	-3	-5	-1	-1	-3
Dagoretti Corner	892	17	16	8	12	9	13	7	8	11
Dar es Salaam	1112	-3	0	0	3	-1	0	-9	-11	-3
Dodoma	603	6	-1	-2	2	7	6	4	16	5
Eldoret	1091	-5	-5	-7	-3	-8	-6	0	3	-4
Entebbe	1354	8	11	17	15	7	12	23	23	14
Garissa	348	21	36	47	29	79	57	25	26	40
Gulu	1379	2	3	6	5	5	5	19	13	7

Table 3.14 (Cont'd)

Location	**Baseline Annual rainfall (mm)**	**Change in rainfall (mm)**								
		2040-2069-CSIRO_rcp45	**2040-2069-CSIRO_rcp85**	**2040-2069-MIROC_rcp45**	**2040-2069-MIROC_rcp85**	**2040-2069-MRI-CGCM3_rcp45**	**2040-2069-MRI-CGCM3_rcp85**	**2040-2069-NorESM1-M_rcp45**	**2040-2069-NorESM1-M_rcp85**	**Av. RFan-2050s**
Jinja	1370	-9	-6	-1	-2	-14	-11	-2	1	-6
Kabale	1232	-27	-25	-19	-17	-23	-24	-15	-19	-21
Kasese	968	-13	-13	-5	-3	-19	-19	13	0	-7
Kigoma	1049	-10	-9	-4	-3	-7	-8	-1	-12	-7
Kisumu	1494	-12	-13	-9	-8	-23	-24	-9	-6	-13
Kitigum	1117	2	6	7	4	1	5	18	11	7
Lamu	872	8	12	23	18	17	6	14	1	12
Lodwar	200	38	24	-3	32	21	76	59	69	39
Makindu	637	4	5	19	7	4	-7	-4	-4	3
Mandera	257	-4	8	16	17	41	10	29	56	22
Marsabiti	614	39	40	39	44	41	48	36	33	40
Masaka	1214	-7	-5	-5	-2	-9	-9	7	4	-3
Mansindi	1215	2	2	10	12	-1	4	22	17	8
Mbarara	990	-13	-13	-11	-11	-13	-17	2	-7	-10
Mbeya	1062	-4	-9	3	-2	-10	-4	0	2	-3
Mtwara	1049	3	2	-1	-7	7	7	-5	-14	-1
Musoma	992	-11	-6	2	3	-14	-7	-3	5	-4
Mwanza	1011	-2	1	7	8	0	-3	4	12	3
Namulonge	1259	-7	-7	0	0	-6	-7	9	7	-2
Narok	751	7	8	-3	16	-1	9	3	2	5
Same	554	21	16	15	24	29	18	11	10	18
Serere	1294	-2	1	2	5	-8	-6	7	12	1
Songea	1088	23	25	24	10	17	26	26	25	22
Soroti	1249	1	8	9	8	-5	2	13	11	6
Tabora	976	-4	-3	-5	5	-5	2	9	9	1
Tororo	1616	-14	-10	-7	-7	-22	-22	-7	-5	-12
Voi	620	-10	-2	-3	2	6	5	5	-1	0
Wajir	312	25	38	31	25	104	44	32	34	42

Table 3. 15 Changes in annual rainfall (mm) for the 2070s

Location	Baseline Annual rainfall (mm)	Change in rainfall (mm)								
		2060-2089-CSIRO_rcp45	2060-2089-CSIRO_rcp85	2060-2089-MIROC_rcp45	2060-2089-MIROC_rcp85	2060-2089-MRI-CGCM3_rcp45	2060-2089-MRI-CGCM3_rcp85	2060-2089-NorESM1-M_rcp45	2060-2089-NorESM1-M_rcp85	Av. RF an-2070s
Arua	1285	5	12	13	13	4	4	24	11	11
Arusha	1058	5	12	9	14	-4	11	10	7	8
Bukoba	2082	-5	-2	-2	1	-3	-1	1	0	-1
Dagoretti Corner	892	20	23	13	15	7	17	17	19	17
Dar es Salaam	1112	-3	1	2	4	0	-6	-8	-11	-3
Dodoma	603	-1	0	-3	-3	2	4	1	12	2
Eldoret	1091	0	2	0	1	-5	-5	5	10	1
Entebbe	1354	14	15	21	23	10	15	28	24	19
Garissa	348	15	25	47	44	86	40	32	19	38
Gulu	1379	5	8	9	4	5	8	21	11	9
Jinja	1370	-5	-3	-1	5	-11	-13	4	3	-3
Kabale	1232	-24	-20	-15	-14	-18	-21	-11	-15	-17
Kasese	968	-14	-10	-3	1	-19	-20	15	4	-6
Kigoma	1049	-14	-12	-3	-7	-15	-10	-6	-17	-11
Kisumu	1494	-9	-7	-5	-4	-20	-18	-5	-2	-9
Kitigum	1117	6	13	11	9	6	14	24	14	12
Lamu	872	2	6	19	16	12	7	9	-2	9
Lodwar	200	44	30	9	32	19	75	70	61	42
Makindu	637	-6	-4	15	9	3	0	0	-14	0
Mandera	257	-7	9	13	20	45	11	32	46	21
Marsabiti	614	36	41	34	35	35	38	36	27	35
Masaka	1214	-3	-5	-2	1	-9	-6	10	5	-1
Mansindi	1215	5	6	14	15	7	8	31	19	13
Mbarara	990	-12	-10	-8	-6	-13	-13	7	-4	-7
Mbeya	1062	-3	-9	-1	-7	-11	-9	-4	-4	-6
Mtwara	1049	-2	1	-4	-8	7	5	-5	-11	-2
Musoma	992	-6	-6	1	2	-5	-8	4	6	-1
Mwanza	1011	-2	4	10	6	1	-1	6	7	4

Table 3.15 (Cont'd)

Location	Baseline Annual rainfall (mm)	Change in rainfall (mm)								
		2060-2089-CSIRO_rcp45	2060-2089-CSIRO_rcp85	2060-2089-MIROC_rcp45	2060-2089-MIROC_rcp85	2060-2089-MRI-CGCM3_rcp45	2060-2089-MRI-CGCM3_rcp85	2060-2089-NorESM1-M_rcp45	2060-2089-NorESM1-M_rcp85	Av. RF an-2070s
Namulonge	1259	0	-2	1	6	-3	-4	12	13	3
Narok	751	9	10	-3	14	5	9	3	6	7
Same	554	11	12	6	16	24	13	8	9	12
Serere	1294	3	8	11	12	-1	2	15	18	9
Songea	1088	23	15	16	8	8	18	17	23	16
Soroti	1249	4	10	14	16	4	7	20	22	12
Tabora	976	-9	-12	-5	-1	-7	-6	2	-1	-5
Tororo	1616	-7	-6	-3	-1	-20	-17	-1	0	-7
Voi	620	-12	-9	5	3	3	3	-10	-12	-4
Wajir	312	27	36	24	20	98	38	28	33	38

Table 3. 16 Changes in the February-June (FMAMJ) rainfall for the 2030s

Location	Baseline - FMAMJ rainfall (mm)	Change in rainfall (mm)								
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85	Av. RF fj-2030s
Arua	455	0	7	-3	1	4	-3	18	1	3
Arusha	683	8	9	-4	5	-4	0	4	4	3
Bukoba	1088	6	8	9	9	8	6	10	11	8
Dagoretti Corner	496	21	19	11	21	1	14	16	12	14
Dar es Salaam	636	6	8	8	10	9	17	-13	-3	5
Dodoma	290	-2	10	-9	-9	10	7	3	-6	0
Eldoret	475	-4	1	-2	-3	-10	-5	-2	1	-3
Entebbe	670	24	26	26	27	24	22	30	26	26
Garissa	134	35	64	36	36	100	98	35	35	55
Gulu	561	8	6	1	4	10	1	20	7	7
Jinja	645	-8	-7	-10	-6	-4	-12	-5	-12	-8

Table 3.16 (Cont'd)

Location	Baseline - FMAMJ rainfall (mm)	Change in rainfall (mm)								
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85	Av. RF fj-2030s
Kabale	516	-17	-16	-12	-7	-6	-13	-24	-17	-14
Kasese	390	-10	-2	-4	-2	-3	-8	-7	-10	-6
Kigoma	471	2	1	-1	9	-9	10	-4	-7	0
Kisumu	724	-5	-4	-1	3	-13	-13	-4	-1	-5
Kitigum	471	6	9	5	13	12	4	26	10	11
Lamu	579	1	5	12	15	5	1	16	2	7
Lodwar	106	49	32	-3	28	27	57	45	35	34
Makindu	222	-4	-3	14	8	2	-1	-8	-14	-1
Mandera	138	8	20	22	21	47	21	16	42	25
Marsabiti	280	64	71	51	41	64	60	58	46	57
Masaka	592	0	7	8	8	8	5	7	9	7
Mansindi	478	6	12	13	8	17	5	33	10	13
Mbarara	376	-9	-4	-6	-1	0	-5	-4	-5	-4
Mbeya	519	-9	-10	-7	-14	-15	-6	-10	-11	-10
Mtwara	603	-11	-7	-11	-6	-6	-5	-23	-15	-11
Musoma	515	10	-3	10	13	0	4	7	10	6
Mwanza	444	8	12	5	17	10	8	9	5	9
Namulonge	539	-5	-5	4	-1	1	-6	8	4	0
Narok	412	20	27	1	12	13	28	17	20	17
Same	319	12	4	-6	-2	2	-2	-1	-4	1
Serere	597	8	11	6	3	9	0	14	9	7
Songea	570	25	15	13	-2	6	14	15	24	14
Soroti	565	11	12	10	12	14	6	22	16	13
Tabora	455	-19	-13	-11	-3	-21	-4	-8	-13	-11
Tororo	768	-10	-3	-6	-7	-7	-10	-2	-4	-6
Voi	237	-5	0	-12	-5	-4	18	-6	-10	-3
Wajir	164	27	59	21	8	103	31	7	14	34

Table 3. 17 Changes in the February-June (FMAMJ) rainfall for the 2050s

Location	Baseline - FMAMJ rainfall (mm)	Change in rainfall (mm)								
		2040-2069-CSIRO_rcp45	2040-2069-CSIRO_rcp85	2040-2069-MIROC_rcp45	2040-2069-MIROC_rcp85	2040-2069-MRI-CGCM3_rcp45	2040-2069-MRI-CGCM3_rcp85	2040-2069-NorESM1-M_rcp45	2040-2069-NorESM1-M_rcp85	Av. RF fj-2050s
Arua	455	-3	0	-6	-5	2	-12	13	-2	-2
Arusha	683	10	13	5	9	2	6	11	7	8
Bukoba	1088	7	5	5	7	11	8	4	9	7
Dagoretti Corner	496	29	32	12	25	16	19	15	19	21
Dar es Salaam	636	8	10	9	15	8	16	-5	-2	7
Dodoma	290	20	6	7	3	21	20	5	8	11
Eldoret	475	-14	-8	-17	-11	-18	-10	-10	-10	-12
Entebbe	670	22	23	26	25	27	26	27	30	26
Garissa	134	49	82	77	58	113	107	65	61	76
Gulu	561	-5	-3	-8	-7	0	-6	15	-3	-2
Jinja	645	-9	-8	-3	-1	-9	-11	-3	-4	-6
Kabale	516	-14	-11	-10	-8	-9	-12	-16	-14	-12
Kasese	390	-14	-10	-2	3	-14	-14	3	1	-6
Kigoma	471	7	5	13	14	5	10	5	-9	6
Kisumu	724	-3	-1	2	2	-6	-7	4	3	-1
Kitigum	471	-4	-1	-10	-7	-5	-3	7	-8	-4
Lamu	579	6	8	16	13	10	6	12	3	9
Lodwar	106	56	42	18	40	42	63	61	34	45
Makindu	222	23	22	30	26	18	18	5	19	20
Mandera	138	8	25	30	27	60	27	37	54	33
Marsabiti	280	62	64	52	61	71	76	54	47	61
Masaka	592	2	6	4	9	8	0	12	8	6
Mansindi	478	0	0	6	14	3	1	24	9	7
Mbarara	376	-4	-2	-1	1	7	-3	4	-1	0
Mbeya	519	0	-1	4	-5	-7	8	-2	4	0
Mtwara	603	2	1	-6	-5	1	9	-7	-17	-3
Musoma	515	3	12	18	14	-1	10	5	8	9
Mwanza	444	14	18	20	24	17	14	14	17	17

Table 3.17 (Cont'd)

Location	Baseline - FMAMJ rainfall (mm)	Change in rainfall (mm)								
		2040-2069-CSIRO_rcp45	2040-2069-CSIRO_rcp85	2040-2069-MIROC_rcp45	2040-2069-MIROC_rcp85	2040-2069-MRI-CGCM3_rcp45	2040-2069-MRI-CGCM3_rcp85	2040-2069-NorESM1-M_rcp45	2040-2069-NorESM1-M_rcp85	Av. RF fj-2050s
Namulonge	539	-5	-9	5	2	5	0	14	5	2
Narok	412	17	19	3	22	-1	12	6	8	11
Same	319	12	10	1	10	11	3	3	2	6
Serere	597	-5	-3	-7	-4	-5	-11	-1	-1	-5
Songea	570	36	31	32	13	13	35	28	32	28
Soroti	565	1	4	-2	-3	-2	1	7	2	1
Tabora	455	5	5	1	7	-2	16	7	3	5
Tororo	768	-13	-8	-2	-4	-8	-14	-6	-9	-8
Voi	237	4	17	2	13	15	18	10	21	12
Wajir	164	37	65	35	34	125	41	48	44	54

Table 3. 18 Changes in the February-June (FMAMJ) rainfall for the 2070s

Location	Baseline - FMAMJ rainfall (mm)	Change in rainfall (mm)								
		2060-2089-CSIRO_rcp45	2060-2089-CSIRO_rcp85	2060-2089-MIROC_rcp45	2060-2089-MIROC_rcp85	2060-2089-MRI-CGCM3_rcp45	2060-2089-MRI-CGCM3_rcp85	2060-2089-NorESM1-M_rcp45	2060-2089-NorESM1-M_rcp85	Av. RF fj-2070s
Arua	455	0	7	-5	4	-1	-9	19	0	2
Arusha	683	14	20	18	23	-3	19	21	17	16
Bukoba	1088	7	8	8	15	12	14	6	6	10
Dagoretti Corner	496	38	41	20	29	19	32	31	34	30
Dar es Salaam	636	6	12	8	15	11	8	-1	-2	7
Dodoma	290	18	11	5	2	10	21	1	5	9
Eldoret	475	-13	-7	-12	-12	-22	-13	-9	-8	-12
Entebbe	670	27	25	30	31	26	25	36	28	28
Garissa	134	42	57	86	72	121	73	72	36	70
Gulu	561	-4	-4	-7	-9	-1	-4	12	-5	-3
Jinja	645	-8	-5	1	5	-1	-14	7	3	-2
Kabale	516	-14	-8	-2	-3	-4	-11	-13	-9	-8
Kasese	390	-14	-14	1	8	-16	-19	6	2	-6
Kigoma	471	-1	2	18	10	-3	4	5	-11	3
Kisumu	724	2	5	10	7	-3	-3	6	8	4

Table 3.18 (Cont'd)

Location	Baseline - FMAMJ rainfall (mm)	Change in rainfall (mm)								
		2060-2089-CSIRO_rcp45	2060-2089-CSIRO_rcp85	2060-2089-MIROC_rcp45	2060-2089-MIROC_rcp85	2060-2089-MRI-CGCM3_rcp45	2060-2089-MRI-CGCM3_rcp85	2060-2089-NorESM1-M_rcp45	2060-2089-NorESM1-M_rcp85	Av. RF fj-2070s
Kitigum	471	1	7	-3	1	1	4	16	0	4
Lamu	579	-1	4	9	8	0	7	0	2	4
Lodwar	106	60	45	33	33	32	61	71	35	46
Makindu	222	12	17	33	38	23	22	7	6	20
Mandera	138	3	27	23	28	63	28	30	45	31
Marsabiti	280	58	67	51	54	60	65	58	41	57
Masaka	592	8	9	10	13	8	5	12	6	9
Mansindi	478	4	1	8	19	7	4	28	12	10
Mbarara	376	-3	1	8	9	2	-1	3	0	3
Mbeya	519	6	-1	7	-1	-7	8	0	-1	1
Mtwara	603	-1	-2	-6	-8	2	10	-5	-16	-3
Musoma	515	10	13	18	11	17	10	16	16	14
Mwanza	444	12	24	28	15	24	15	14	11	18
Namulonge	539	2	-5	7	8	9	1	18	12	7
Narok	412	19	25	3	25	12	18	9	14	16
Same	319	2	11	1	11	4	4	-3	7	5
Serere	597	-5	0	-1	2	2	-9	4	1	-1
Songea	570	40	29	34	16	10	33	25	31	27
Soroti	565	3	8	5	0	5	4	10	7	5
Tabora	455	2	1	4	9	-4	12	6	-3	3
Tororo	768	-5	-4	-1	0	-6	-6	-1	-3	-3
Voi	237	1	2	7	10	18	16	2	15	9
Wajir	164	44	61	30	27	115	32	41	46	49

Table 3. 19 Changes in the August-December (ASOND) rainfall for the 2030s

Location	Baseline - ASOND-rainfall (mm)	Change in rainfall (mm)								
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85	Av. RF ad-2030s
Arua	661	12	10	13	14	4	8	25	20	13
Arusha	271	-3	9	9	5	19	14	12	3	9
Bukoba	777	-17	-17	-16	-10	-17	-11	-2	-3	-12
Dagoretti Corner	311	15	12	7	3	21	12	10	10	11
Dar es Salaam	385	-21	-16	-8	-3	-15	-25	-13	-21	-15
Dodoma	173	-1	2	26	26	31	1	8	42	17
Eldoret	419	-4	-5	-7	3	-8	-16	5	10	-3
Entebbe	563	-6	-6	0	5	-10	-6	22	22	3
Garissa	187	15	19	41	34	82	24	23	26	33
Gulu	650	5	7	16	16	5	11	34	30	16
Jinja	583	-8	-6	6	15	-17	-9	7	20	1
Kabale	618	-39	-33	-28	-19	-37	-33	-10	-22	-28
Kasese	521	-17	-14	-18	-9	-31	-23	7	-4	-14
Kigoma	426	-7	-8	-11	-6	-10	-13	1	4	-6
Kisumu	588	-17	-21	-15	-8	-36	-35	-13	-8	-19
Kitigum	483	2	10	20	16	3	7	22	32	14
Lamu	188	10	15	23	22	39	1	10	-25	12
Lodwar	68	-17	-12	-19	-6	-31	103	64	198	35
Makindu	369	-2	-3	9	2	0	-14	-1	-12	-3
Mandera	109	-13	-6	6	25	34	-12	29	70	17
Marsabiti	285	27	25	39	45	19	33	37	52	35
Masaka	527	-21	-16	-17	-14	-23	-19	2	4	-13
Mansindi	615	-5	-6	3	4	-16	-4	21	26	3
Mbarara	549	-22	-20	-17	-17	-27	-22	5	-6	-16
Mbeya	296	14	1	17	11	-4	-8	27	19	10
Mtwara	226	5	15	15	3	50	5	8	4	13
Musoma	366	-18	-18	-14	4	-20	-17	3	7	-9
Mwanza	440	2	3	3	10	-5	-6	20	26	7
Namulonge	601	-14	-15	-2	5	-14	-8	14	18	-2

Table 3.19 (Cont'd)

Location	Baseline - ASOND-rainfall (mm)	Change in rainfall (mm)								
		2020-2049-CSIRO_rcp45	**2020-2049-CSIRO_rcp85**	**2020-2049-MIROC_rcp45**	**2020-2049-MIROC_rcp85**	**2020-2049-MRI-CGCM3_rcp45**	**2020-2049-MRI-CGCM3_rcp85**	**2020-2049-NorESM1-M_rcp45**	**2020-2049-NorESM1-M_rcp85**	**Av. RF ad-2030s**
Namulonge	601	-14	-15	-2	5	-14	-8	14	18	-2
Narok	227	9	4	2	28	11	16	20	13	13
Same	175	40	36	50	67	79	59	46	31	51
Serere	573	-12	-10	3	7	-12	-16	7	15	-2
Songea	242	43	54	35	33	53	36	42	41	42
Soroti	548	-2	0	14	7	-14	0	5	15	3
Tabora	338	3	5	10	18	18	13	20	28	14
Tororo	682	-24	-19	-13	-7	-34	-34	-13	-3	-18
Voi	332	-8	-6	12	7	18	3	13	-17	3
Wajir	128	15	14	52	31	79	61	52	51	44

Table 3. 20 Changes in the August-December (ASOND) rainfall for the 2050s

Location	Baseline - ASOND-rainfall (mm)	Change in rainfall (mm)								
		2040-2069-CSIRO_rcp45	**2040-2069-CSIRO_rcp85**	**2040-2069-MIROC_rcp45**	**2040-2069-MIROC_rcp85**	**2040-2069-MRI-CGCM3_rcp45**	**2040-2069-MRI-CGCM3_rcp85**	**2040-2069-NorESM1-M_rcp45**	**2040-2069-NorESM1-M_rcp85**	**Av. RF ad-2050s**
Arua	661	14	12	15	17	9	8	31	19	16
Arusha	271	1	0	-7	-3	6	7	3	-7	0
Bukoba	777	-16	-13	-14	-12	-19	-17	-4	-8	-13
Dagoretti Corner	311	8	-1	8	2	6	12	8	1	5
Dar es Salaam	385	-23	-17	-14	-13	-15	-28	-17	-28	-19
Dodoma	173	-6	-6	5	11	17	-2	-2	40	7
Eldoret	419	2	-1	0	5	1	-5	13	18	4
Entebbe	563	-11	-4	4	6	-16	-3	21	18	2
Garissa	187	-1	9	27	11	65	25	7	12	19
Gulu	650	6	8	18	16	10	12	27	28	16

Table 3.20 (Cont'd)

Location	Baseline - ASOND-rainfall (mm)	Change in rainfall (mm)								
		2040-2069-CSIRO_rcp45	2040-2069-CSIRO_rcp85	2040-2069-MIROC_rcp45	2040-2069-MIROC_rcp85	2040-2069-MRI-CGCM3_rcp45	2040-2069-MRI-CGCM3_rcp85	2040-2069-NorESM1-M_rcp45	2040-2069-NorESM1-M_rcp85	Av. RF ad-2050s
Jinja	583	-5	-2	-3	2	-16	-10	1	8	-3
Kabale	618	-39	-39	-33	-26	-36	-36	-17	-25	-31
Kasese	521	-18	-18	-12	-12	-26	-26	15	-2	-13
Kigoma	426	-24	-19	-22	-22	-14	-22	-9	-14	-18
Kisumu	588	-16	-22	-16	-9	-37	-39	-15	-7	-20
Kitigum	483	8	13	20	14	7	11	29	31	17
Lamu	188	30	36	60	47	71	20	39	-1	38
Lodwar	68	2	1	-19	11	-15	140	88	138	43
Makindu	369	-7	-7	9	-6	-7	-23	-8	-17	-8
Mandera	109	-15	-5	5	10	26	-2	29	62	14
Marsabiti	285	17	16	21	24	13	21	22	21	19
Masaka	527	-16	-16	-16	-12	-26	-16	2	6	-12
Mansindi	615	1	-1	9	10	-7	2	23	24	8
Mbarara	549	-24	-25	-28	-25	-32	-30	-2	-11	-22
Mbeya	296	8	-7	11	12	-3	-7	9	7	4
Mtwara	226	12	17	20	4	32	5	9	-4	12
Musoma	366	-23	-21	-15	-1	-23	-21	-6	9	-12
Mwanza	440	-13	-4	-2	-2	-11	-13	-1	17	-4
Namulonge	601	-9	-7	-10	-1	-14	-15	3	11	-5
Narok	227	-1	2	-16	16	4	11	15	4	4
Same	175	40	20	32	53	68	42	30	18	38
Serere	573	-5	0	8	11	-12	-9	12	19	3
Songea	242	23	42	27	27	44	33	42	26	33
Soroti	548	-3	4	14	16	-11	0	14	18	6
Tabora	338	-4	1	-8	12	6	5	13	26	6
Tororo	682	-16	-14	-10	-4	-34	-31	-4	4	-14
Voi	332	-18	-15	-8	-3	3	-2	10	-13	-6
Wajir	128	17	9	28	16	95	61	25	36	36

Table 3. 21 Changes in the August-December (ASOND) rainfall for the 2070s

Location	**Baseline - ASOND-rainfall (mm)**	**Change in rainfall (mm)**								
		2060-2089-CSIRO_rcp45	**2060-2089-CSIRO_rcp85**	**2060-2089-MIROC_rcp45**	**2060-2089-MIROC_rcp85**	**2060-2089-MRI-CGCM3_rcp45**	**2060-2089-MRI-CGCM3_rcp85**	**2060-2089-NorESM1-M_rcp45**	**2060-2089-NorESM1-M_rcp85**	**Av. RF ad-2070s**
Arua	661	12	16	23	23	7	11	32	24	18
Arusha	271	-2	2	-1	4	1	2	-5	-5	-1
Bukoba	777	-16	-12	-15	-13	-18	-17	-1	-4	-12
Dagoretti Corner	311	5	7	8	1	-1	5	14	8	6
Dar es Salaam	385	-22	-18	-11	-12	-16	-31	-17	-27	-19
Dodoma	173	-8	-2	2	6	6	-7	-3	42	4
Eldoret	419	11	9	7	15	7	-12	23	34	12
Entebbe	563	0	3	10	18	-8	5	22	22	9
Garissa	187	0	9	21	30	67	22	13	17	22
Gulu	650	12	18	21	17	12	15	32	28	19
Jinja	583	2	2	-5	6	-19	-14	4	5	-2
Kabale	618	-35	-32	-32	-24	-31	-33	-13	-21	-28
Kasese	521	-19	-13	-11	-8	-28	-27	19	2	-10
Kigoma	426	-24	-20	-26	-21	-18	-20	-17	-20	-21
Kisumu	588	-17	-13	-16	-7	-35	-31	-10	-2	-16
Kitigum	483	11	22	23	22	14	25	37	32	23
Lamu	188	21	24	63	47	78	30	45	-7	38
Lodwar	68	10	15	-15	19	-5	138	99	115	47
Makindu	369	-15	-16	0	-9	-12	-14	-2	-24	-11
Mandera	109	-12	-6	9	19	34	-1	43	51	17
Marsabiti	285	16	16	15	17	11	13	18	15	15
Masaka	527	-15	-17	-17	-9	-25	-15	10	5	-10
Mansindi	615	4	8	17	13	4	5	34	28	14
Mbarara	549	-25	-24	-25	-23	-28	-27	1	-11	-20
Mbeya	296	1	-5	1	-7	-5	-17	1	5	-3
Mtwara	226	3	14	7	3	29	4	9	3	9
Musoma	366	-20	-23	-20	0	-26	-23	-3	6	-14
Mwanza	440	-11	-6	-4	5	-12	-8	4	13	-2
Namulonge	601	-1	-3	-8	4	-13	-13	5	16	-2

Table 3.21 (Cont'd)

Location	Baseline - ASOND-rainfall (mm)	Change in rainfall (mm)								
		2060-2089-CSIRO_rcp45	2060-2089-CSIRO_rcp85	2060-2089-MIROC_rcp45	2060-2089-MIROC_rcp85	2060-2089-MRI-CGCM3_rcp45	2060-2089-MRI-CGCM3_rcp85	2060-2089-NorESM1-M_rcp45	2060-2089-NorESM1-M_rcp85	Av. RF ad-2070s
Narok	227	-2	-2	-13	11	-1	7	12	4	2
Same	175	29	15	18	37	71	29	33	9	30
Serere	573	4	8	19	19	-11	4	23	34	13
Songea	242	29	30	12	22	32	27	33	34	27
Soroti	548	2	6	21	28	-3	6	24	40	15
Tabora	338	-10	-14	-12	3	5	-10	1	11	-3
Tororo	682	-10	-7	1	6	-30	-27	0	6	-8
Voi	332	-18	-14	4	0	-4	-1	-11	-27	-9
Wajir	128	12	12	20	16	95	56	27	35	34

APPENDIX D: Projected mean temperature

Table 3. 22 Annual mean temperatures for the 2030s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Location	Baseline annual Tav (C)	Mean temperature change (^{0}C)							
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85
Arua	24.4	-0.9	-1.0	-1.0	-1.0	-0.8	-1.1	-1.4	-1.2
Arusha	14.0	5.7	5.7	5.8	5.8	5.6	5.7	5.8	5.8
Bukoba	22.2	-0.5	-0.6	-0.7	-0.7	-0.8	-0.8	-0.8	-0.8
Dagoretti Corner	20.5	-2.3	-2.3	-2.3	-2.2	-2.4	-2.4	-2.2	-2.2
Dar es Salaam	26.5	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1
Dodoma	23.4	-0.4	-0.4	-0.3	-0.2	-0.5	-0.6	-0.5	-0.5
Eldoret	18.4	-1.0	-1.0	-1.0	-1.0	-0.9	-0.9	-1.1	-1.1
Entebbe	22.8	-0.6	-0.7	-0.8	-0.8	-0.7	-0.7	-1.1	-0.9
Garissa	28.9	0.7	0.7	0.6	0.7	0.6	0.6	0.7	0.9
Gulu	24.5	-0.7	-0.8	-0.9	-0.9	-0.8	-0.9	-1.5	-1.1
Jinja	21.9	0.8	0.8	0.7	0.7	0.9	0.9	0.4	0.6
Kabale	18.2	-0.4	-0.5	-0.5	-0.5	-0.6	-0.6	-0.6	-0.7
Kasese	24.4	-0.7	-0.8	-0.7	-0.7	-0.1	-0.1	-1.0	-0.9
Kigoma	24.0	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.2
Kisumu	23.6	-0.2	-0.3	-0.3	-0.2	0.4	0.4	-0.3	-0.3
Kitigum	25.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.7	-1.0	-0.7
Lamu	27.8	-0.5	-0.4	-0.4	-0.4	-0.5	-0.5	-0.4	-0.4
Lodwar	29.8	0.0	-0.1	0.1	0.1	-0.2	-0.3	-0.2	-0.1
Makindu	24.2	-1.2	-1.2	-1.2	-1.2	-1.3	-1.2	-1.1	-1.0
Mandera	29.7	-0.1	-0.1	-0.2	-0.2	-0.3	-0.2	-0.2	-0.2
Marsabiti	24.4	-4.0	-4.1	-4.1	-4.0	-4.2	-4.3	-4.1	-4.0
Masaka	21.7	0.0	-0.1	-0.2	-0.2	0.0	0.0	-0.4	-0.3
Mansindi	24.2	-0.7	-0.8	-0.9	-0.8	-0.6	-0.7	-1.5	-1.1
Mbarara	21.2	-0.4	-0.5	-0.5	-0.5	-0.3	-0.3	-0.7	-0.7
Mbeya	20.0	-1.5	-1.6	-1.5	-1.4	-1.8	-1.8	-1.7	-1.7
Mtwara	26.1	0.7	0.7	0.8	0.8	0.6	0.6	0.8	0.8
Musoma	22.9	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.6
Mwanza	23.3	0.0	-0.1	-0.1	-0.1	-0.2	-0.2	-0.3	-0.2
Namulonge	22.8	-0.4	-0.5	-0.6	-0.6	-0.4	-0.5	-1.0	-0.8
Narok	17.7	-0.4	-0.4	-0.3	-0.3	-0.5	-0.6	-0.4	-0.3

Table 3.22 (Cont'd)

Location	Baseline annual Tav (C)	Mean temperature change (^{0}C)							
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85
Same	24.5	-1.3	-1.3	-1.2	-1.2	-1.4	-1.3	-1.2	-1.2
Serere	24.9	-0.5	-0.6	-0.6	-0.6	-0.5	-0.5	-0.9	-0.8
Songea	22.3	-0.8	-0.9	-0.8	-0.6	-1.0	-1.0	-0.9	-0.9
Soroti	25.3	-0.6	-0.7	-0.8	-0.8	-0.7	-0.7	-1.1	-0.9
Tabora	23.8	-0.1	-0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.2
Tororo	22.9	0.1	0.1	0.1	0.1	0.8	0.8	-0.1	-0.1
Voi	26.2	-0.9	-0.9	-0.9	-0.9	-1.0	-0.9	-0.8	-0.8
Wajir	28.9	-0.7	-0.7	-0.7	-0.7	-0.9	-0.9	-0.8	-0.6

Table 3. 23 Annual mean temperatures for 2050s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Location	Baseline annual Tav (^{0}C)	Mean temperature change (^{0}C)							
		2040-2069-CSIRO_rcp45	2040-2069-CSIRO_rcp85	2040-2069-MIROC_rcp45	2040-2069-MIROC_rcp85	2040-2069-MRI-CGCM3_rcp45	2040-2069-MRI-CGCM3_rcp85	2040-2069-NorESM1-M_rcp45	2040-2069-NorESM1-M_rcp85
Arua	24.4	-0.8	-0.9	-0.9	-0.9	-0.7	-1.0	-1.3	-1.1
Arusha	14.0	5.8	5.8	5.9	5.9	5.7	5.7	5.9	5.9
Bukoba	22.2	-0.4	-0.5	-0.6	-0.6	-0.7	-0.7	-0.7	-0.7
Dagoretti Corner	20.5	-2.3	-2.2	-2.2	-2.2	-2.3	-2.4	-2.1	-2.1
Dar es Salaam	26.5	-0.1	-0.1	0.0	0.0	-0.1	-0.1	0.0	0.0
Dodoma	23.4	-0.3	-0.3	-0.2	-0.1	-0.4	-0.5	-0.4	-0.4
Eldoret	18.4	-0.9	-0.9	-0.9	-0.9	-0.8	-0.8	-1.0	-1.0
Entebbe	22.8	-0.5	-0.6	-0.7	-0.7	-0.6	-0.6	-1.0	-0.9
Garissa	28.9	0.7	0.8	0.7	0.7	0.7	0.6	0.8	0.9
Gulu	24.5	-0.6	-0.7	-0.8	-0.8	-0.7	-0.8	-1.4	-1.0
Jinja	21.9	0.9	0.9	0.8	0.8	1.0	1.0	0.5	0.6
Kabale	18.2	-0.3	-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.6
Kasese	24.4	-0.6	-0.7	-0.6	-0.6	0.0	0.0	-0.9	-0.8
Kigoma	24.0	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.3
Kisumu	23.6	-0.2	-0.2	-0.2	-0.1	0.5	0.5	-0.3	-0.3

Table 3.23 (Cont'd)

Location	Baseline annual Tav (^0C)	Mean temperature change (^0C)							
		2040-2069-CSIRO_rcp45	2040-2069-CSIRO_rcp85	2040-2069-MIROC_rcp45	2040-2069-MIROC_rcp85	2040-2069-MRI-CGCM3_rcp45	2040-2069-MRI-CGCM3_rcp85	2040-2069-NorESM1-M_rcp45	2040-2069-NorESM1-M_rcp85
Kitigum	25.4	-0.3	-0.4	-0.5	-0.4	-0.4	-0.6	-0.9	-0.6
Lamu	27.8	-0.4	-0.4	-0.4	-0.4	-0.5	-0.5	-0.3	-0.3
Lodwar	29.8	0.1	0.0	0.1	0.1	-0.2	-0.2	-0.2	-0.1
Makindu	24.2	-1.1	-1.1	-1.2	-1.1	-1.2	-1.1	-1.0	-1.0
Mandera	29.7	0.0	0.0	-0.1	-0.1	-0.2	-0.1	-0.2	-0.1
Marsabiti	24.4	-4.0	-4.0	-4.0	-3.9	-4.2	-4.2	-4.1	-3.9
Masaka	21.7	0.1	0.0	-0.1	-0.1	0.1	0.1	-0.3	-0.2
Mansindi	24.2	-0.6	-0.7	-0.8	-0.8	-0.5	-0.6	-1.4	-1.0
Mbarara	21.2	-0.3	-0.4	-0.4	-0.4	-0.3	-0.2	-0.6	-0.6
Mbeya	20.0	-1.5	-1.5	-1.5	-1.3	-1.7	-1.7	-1.6	-1.6
Mtwara	26.1	0.7	0.7	0.8	0.8	0.7	0.7	0.8	0.8
Musoma	22.9	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7
Mwanza	23.3	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.2	-0.1
Namulonge	22.8	-0.3	-0.4	-0.5	-0.5	-0.4	-0.4	-0.9	-0.7
Narok	17.7	-0.3	-0.3	-0.3	-0.2	-0.4	-0.5	-0.3	-0.2
Same	24.5	-1.2	-1.2	-1.2	-1.2	-1.3	-1.2	-1.1	-1.1
Serere	24.9	-0.4	-0.5	-0.5	-0.5	-0.4	-0.4	-0.9	-0.7
Songea	22.3	-0.8	-0.8	-0.7	-0.6	-0.9	-1.0	-0.8	-0.9
Soroti	25.3	-0.6	-0.6	-0.7	-0.7	-0.6	-0.6	-1.0	-0.8
Tabora	23.8	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.2	-0.1
Tororo	22.9	0.2	0.2	0.2	0.2	0.9	0.9	0.0	0.0
Voi	26.2	-0.8	-0.8	-0.8	-0.8	-0.9	-0.8	-0.7	-0.7
Wajir	28.9	-0.6	-0.6	-0.7	-0.6	-0.8	-0.8	-0.7	-0.6

Table 3. 24 Annual mean temperatures for 2070s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Location	Baseline annual Tav (^{0}C)	Mean temperature change (^{0}C)							
		2060-2089-CSIRO_rcp45	2060-2089-CSIRO_rcp85	2060-2089-MIROC_rcp45	2060-2089-MIROC_rcp85	2060-2089-MRI-CGCM3_rcp45	2060-2089-MRI-CGCM3_rcp85	2060-2089-NorESM1-M_rcp45	2060-2089-NorESM1-M_rcp85
Arua	24.4	-0.8	-0.9	-1.0	-0.9	-0.7	-1.0	-1.3	-1.1
Arusha	14.0	5.8	5.8	5.9	5.9	5.7	5.7	5.9	5.9
Bukoba	22.2	-0.5	-0.5	-0.6	-0.6	-0.7	-0.7	-0.7	-0.7
Dagoretti Corner	20.5	-2.3	-2.2	-2.2	-2.2	-2.3	-2.4	-2.2	-2.1
Dar es Salaam	26.5	-0.1	-0.1	0.0	0.0	-0.2	-0.1	0.0	0.0
Dodoma	23.4	-0.3	-0.3	-0.2	-0.1	-0.4	-0.5	-0.4	-0.4
Eldoret	18.4	-0.9	-1.0	-0.9	-0.9	-0.8	-0.9	-1.0	-1.0
Entebbe	22.8	-0.6	-0.6	-0.7	-0.7	-0.6	-0.6	-1.0	-0.9
Garissa	28.9	0.8	0.8	0.6	0.7	0.6	0.7	0.7	0.9
Gulu	24.5	-0.6	-0.7	-0.8	-0.8	-0.7	-0.9	-1.4	-1.0
Jinja	21.9	0.9	0.8	0.8	0.8	1.0	1.0	0.5	0.6
Kabale	18.2	-0.3	-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.6
Kasese	24.4	-0.6	-0.7	-0.7	-0.7	0.0	0.0	-0.9	-0.8
Kigoma	24.0	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.3
Kisumu	23.6	-0.2	-0.2	-0.2	-0.2	0.5	0.5	-0.3	-0.3
Kitigum	25.4	-0.3	-0.4	-0.5	-0.5	-0.4	-0.6	-0.9	-0.6
Lamu	27.8	-0.4	-0.4	-0.4	-0.4	-0.5	-0.5	-0.3	-0.3
Lodwar	29.8	0.0	0.0	0.1	0.1	-0.2	-0.2	-0.2	-0.1
Makindu	24.2	-1.1	-1.1	-1.2	-1.1	-1.2	-1.1	-1.0	-1.0
Mandera	29.7	0.0	0.0	-0.1	-0.1	-0.2	-0.2	-0.2	-0.1
Marsabiti	24.4	-4.0	-4.0	-4.0	-3.9	-4.2	-4.2	-4.1	-3.9
Masaka	21.7	0.1	0.0	-0.1	-0.1	0.1	0.1	-0.3	-0.2
Mansindi	24.2	-0.6	-0.7	-0.8	-0.8	-0.5	-0.6	-1.4	-1.0
Mbarara	21.2	-0.3	-0.4	-0.4	-0.4	-0.3	-0.3	-0.6	-0.6
Mbeya	20.0	-1.5	-1.5	-1.5	-1.3	-1.7	-1.7	-1.7	-1.6
Mtwara	26.1	0.7	0.7	0.8	0.8	0.6	0.7	0.8	0.8
Musoma	22.9	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7
Mwanza	23.3	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.2	-0.2
Namulonge	22.8	-0.3	-0.4	-0.5	-0.5	-0.4	-0.4	-0.9	-0.7
Narok	17.7	-0.3	-0.3	-0.3	-0.2	-0.4	-0.5	-0.3	-0.2
Same	24.5	-1.2	-1.2	-1.2	-1.2	-1.3	-1.2	-1.1	-1.1
Serere	24.9	-0.4	-0.5	-0.6	-0.6	-0.4	-0.5	-0.9	-0.7

Table 3.24 (Cont'd)

Location	Baseline annual Tav (^{0}C)	Mean temperature change (^{0}C)							
		2060-2089-CSIRO_rcp45	2060-2089-CSIRO_rcp85	2060-2089-MIROC_rcp45	2060-2089-MIROC_rcp85	2060-2089-MRI-CGCM3_rcp45	2060-2089-MRI-CGCM3_rcp85	2060-2089-NorESM1-M_rcp45	2060-2089-NorESM1-M_rcp85
Songea	22.3	-0.8	-0.8	-0.7	-0.6	-0.9	-1.0	-0.8	-0.9
Soroti	25.3	-0.6	-0.7	-0.7	-0.7	-0.6	-0.7	-1.0	-0.9
Tabora	23.8	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.2	-0.2
Tororo	22.9	0.2	0.1	0.1	0.1	0.8	0.9	0.0	0.0
Voi	26.2	-0.8	-0.8	-0.8	-0.8	-1.0	-0.8	-0.7	-0.7
Wajir	28.9	-0.6	-0.6	-0.7	-0.6	-0.8	-0.8	-0.7	-0.6

Table 3. 25 Mean temperatures for February-June in 2030s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Location	Baseline Tav FMAMJ (^{0}C)	Mean temperature change (^{0}C)							
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85
Arua	24.9	-0.8	-0.9	-1.0	-1.0	-1.0	-1.0	-1.5	-1.2
Arusha	14.2	5.8	5.8	5.9	5.9	5.7	5.8	5.9	5.9
Bukoba	22.4	-0.6	-0.7	-0.8	-0.8	-0.9	-0.9	-0.8	-0.9
Dagoretti Corner	20.9	-2.3	-2.2	-2.2	-2.2	-2.3	-2.4	-2.2	-2.2
Dar es Salaam	26.6	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.3
Dodoma	23.3	-0.4	-0.4	-0.3	-0.2	-0.5	-0.6	-0.6	-0.6
Eldoret	18.9	-1.2	-1.2	-1.2	-1.2	-1.0	-1.1	-1.3	-1.3
Entebbe	23.1	-0.7	-0.8	-0.9	-0.8	-0.9	-0.9	-1.2	-1.0
Garissa	29.7	0.8	0.7	0.7	0.7	0.6	0.4	0.8	0.8
Gulu	25.0	-0.8	-0.9	-1.0	-1.0	-1.1	-1.0	-1.6	-1.2
Jinja	22.2	0.8	0.7	0.6	0.7	0.8	0.8	0.2	0.5
Kabale	18.3	-0.5	-0.6	-0.7	-0.6	-0.7	-0.6	-0.6	-0.7
Kasese	24.5	-0.5	-0.7	-0.6	-0.6	-0.2	0.0	-0.7	-0.7
Kigoma	23.9	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.2
Kisumu	23.9	-0.5	-0.5	-0.5	-0.5	0.4	0.3	-0.6	-0.6
Kitigum	26.1	-0.4	-0.5	-0.6	-0.6	-0.6	-0.7	-1.1	-0.7
Lamu	28.3	-0.6	-0.6	-0.7	-0.6	-0.7	-0.7	-0.6	-0.7
Lodwar	30.2	0.0	-0.1	0.0	0.0	-0.3	-0.4	-0.2	0.0

Table 3.25 (Cont'd)

Location	Baseline Tav FMAMJ (^{0}C)	Mean temperature change (^{0}C)							
		2020-2049-CSIRO_rcp45	2020-2049-CSIRO_rcp85	2020-2049-MIROC_rcp45	2020-2049-MIROC_rcp85	2020-2049-MRI-CGCM3_rcp45	2020-2049-MRI-CGCM3_rcp85	2020-2049-NorESM1-M_rcp45	2020-2049-NorESM1-M_rcp85
Makindu	24.9	-1.0	-1.0	-1.1	-1.1	-1.2	-1.1	-0.9	-1.0
Mandera	30.5	-0.1	-0.2	-0.2	-0.2	-0.4	-0.4	-0.3	-0.3
Marsabiti	25.0	-3.8	-3.9	-3.9	-3.8	-4.1	-4.2	-4.0	-3.9
Masaka	21.8	0.0	-0.1	-0.3	-0.3	-0.1	-0.1	-0.5	-0.4
Mansindi	24.5	-0.7	-0.8	-0.8	-0.8	-0.9	-0.7	-1.6	-1.0
Mbarara	21.4	-0.3	-0.4	-0.5	-0.4	-0.3	-0.2	-0.6	-0.5
Mbeya	19.7	-1.7	-1.7	-1.7	-1.6	-1.9	-2.0	-2.0	-1.8
Mtwara	25.7	1.4	1.4	1.5	1.5	1.3	1.3	1.4	1.4
Musoma	22.7	0.9	0.9	0.8	0.9	1.0	0.8	0.7	0.7
Mwanza	23.2	0.1	0.1	0.0	0.0	-0.1	-0.2	-0.2	-0.2
Namulonge	23.1	-0.6	-0.7	-0.6	-0.5	-0.7	-0.5	-1.0	-0.8
Narok	18.2	-0.6	-0.5	-0.5	-0.5	-0.6	-0.8	-0.5	-0.6
Same	24.8	-1.1	-1.1	-1.1	-1.1	-1.4	-1.2	-1.1	-1.1
Serere	25.4	-0.8	-1.0	-1.0	-1.0	-1.0	-0.9	-1.4	-1.2
Songea	22.0	-0.8	-0.8	-0.8	-0.7	-0.9	-1.0	-1.0	-0.9
Soroti	25.7	-0.8	-0.9	-1.0	-1.0	-0.9	-0.9	-1.3	-1.1
Tabora	23.2	-0.1	-0.2	-0.2	-0.2	-0.2	-0.5	-0.4	-0.3
Tororo	23.2	0.0	-0.1	-0.1	0.0	0.7	0.8	-0.3	-0.3
Voi	26.8	-0.6	-0.6	-0.6	-0.7	-0.8	-0.7	-0.6	-0.7
Wajir	29.7	-0.7	-0.8	-0.7	-0.7	-1.0	-1.0	-0.8	-0.7

Table 3. 26 Mean temperatures for February-June in 2050s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Name of location	Baseline Tav FMAMJ (^{0}C)	Mean temperature change (^{0}C)							
		2040-2069-CSIRO_rcp45	2040-2069-CSIRO_rcp85	2040-2069-MIROC_rcp45	2040-2069-MIROC_rcp85	2040-2069-MRI-CGCM3_rcp45	2040-2069-MRI-CGCM3_rcp85	2040-2069-NorESM1-M_rcp45	2040-2069-NorESM1-M_rcp85
Arua	24.9	-0.7	-0.8	-0.9	-0.8	-0.8	-0.9	-1.3	-1.0
Arusha	14.2	5.9	5.9	5.9	5.9	5.7	5.8	5.9	5.9
Bukoba	22.4	-0.5	-0.6	-0.7	-0.7	-0.8	-0.8	-0.8	-0.8
Dagoretti Corner	20.9	-2.2	-2.2	-2.2	-2.2	-2.3	-2.3	-2.1	-2.1
Dar esSalaam	26.6	0.4	0.4	0.5	0.4	0.4	0.3	0.4	0.4
Dodoma	23.3	-0.4	-0.3	-0.2	-0.1	-0.4	-0.5	-0.5	-0.5
Eldoret	18.9	-1.0	-1.1	-1.1	-1.0	-0.9	-1.0	-1.1	-1.1
Entebbe	23.1	-0.6	-0.7	-0.8	-0.8	-0.8	-0.8	-1.2	-1.0
Garissa	29.7	0.8	0.8	0.6	0.7	0.5	0.5	0.7	0.8
Gulu	25.0	-0.6	-0.7	-0.8	-0.8	-0.9	-0.8	-1.5	-0.9
Jinja	22.2	0.8	0.7	0.7	0.7	0.8	0.9	0.3	0.5
Kabale	18.3	-0.4	-0.5	-0.5	-0.6	-0.6	-0.5	-0.6	-0.7
Kasese	24.5	-0.4	-0.5	-0.5	-0.5	-0.1	0.1	-0.7	-0.6
Kigoma	23.9	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3
Kisumu	23.9	-0.4	-0.5	-0.5	-0.4	0.4	0.4	-0.6	-0.6
Kitigum	26.1	-0.2	-0.3	-0.4	-0.4	-0.5	-0.5	-0.9	-0.5
Lamu	28.3	-0.5	-0.5	-0.5	-0.5	-0.6	-0.6	-0.5	-0.6
Lodwar	30.2	0.0	-0.1	-0.1	-0.1	-0.2	-0.4	-0.2	0.0
Makindu	24.9	-1.0	-1.0	-1.1	-1.1	-1.2	-1.1	-1.0	-1.0
Mandera	30.5	-0.1	-0.2	-0.2	-0.2	-0.4	-0.4	-0.3	-0.3
Marsabiti	25.0	-3.8	-3.9	-3.8	-3.8	-4.1	-4.2	-3.9	-3.8
Masaka	21.8	0.0	-0.1	-0.2	-0.2	-0.1	-0.1	-0.4	-0.3
Mansindi	24.5	-0.5	-0.6	-0.7	-0.6	-0.7	-0.5	-1.4	-0.9
Mbarara	21.4	-0.3	-0.4	-0.5	-0.4	-0.3	-0.2	-0.6	-0.6
Mbeya	19.7	-1.6	-1.6	-1.6	-1.5	-1.8	-1.9	-1.9	-1.7
Mtwara	25.7	1.4	1.4	1.5	1.5	1.4	1.3	1.4	1.4
Musoma	22.7	0.9	0.9	0.9	0.9	1.0	0.8	0.8	0.7
Mwanza	23.2	0.2	0.1	0.1	0.1	0.0	-0.1	-0.1	-0.1
Namulonge	23.1	-0.5	-0.6	-0.6	-0.5	-0.6	-0.5	-1.0	-0.7
Narok	18.2	-0.5	-0.5	-0.5	-0.4	-0.6	-0.7	-0.4	-0.5
Same	24.8	-1.0	-1.1	-1.0	-1.1	-1.3	-1.1	-1.0	-1.1
Serere	25.4	-0.7	-0.8	-0.9	-0.8	-0.8	-0.7	-1.2	-1.0

Table 3.26 (Cont'd)

Name of location	**Baseline Tav FMAMJ (^{0}C)**	**Mean temperature change (^{0}C)**							
		2040-2069-CSIRO_rcp45	**2040-2069-CSIRO_rcp85**	**2040-2069-MIROC_rcp45**	**2040-2069-MIROC_rcp85**	**2040-2069-MRI-CGCM3_rcp45**	**2040-2069-MRI-CGCM3_rcp85**	**2040-2069-NorESM1-M_rcp45**	**2040-2069-NorESM1-M_rcp85**
Songea	22.0	-0.7	-0.7	-0.7	-0.6	-0.8	-1.0	-0.9	-0.8
Soroti	25.7	-0.6	-0.7	-0.8	-0.8	-0.8	-0.7	-1.1	-0.9
Tabora	23.2	-0.1	-0.1	-0.1	-0.1	-0.2	-0.4	-0.4	-0.3
Tororo	23.2	0.1	0.0	0.0	0.1	0.8	0.9	-0.1	-0.1
Voi	26.8	-0.5	-0.6	-0.6	-0.7	-0.8	-0.7	-0.6	-0.6
Wajir	29.7	-0.7	-0.7	-0.7	-0.7	-1.0	-1.0	-0.8	-0.7

Table 3. 27 Mean temperatures for February-June in 2070s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Name of location	**Baseline Tav FMAMJ (^{0}C)**	**Mean temperature change (^{0}C)**							
		2060-2089-CSIRO_rcp45	**2060-2089-CSIRO_rcp85**	**2060-2089-MIROC_rcp45**	**2060-2089-MIROC_rcp85**	**2060-2089-MRI-CGCM3_rcp45**	**2060-2089-MRI-CGCM3_rcp85**	**2060-2089-NorESM1-M_rcp45**	**2060-2089-NorESM1-M_rcp85**
Arua	24.9	-0.8	-0.9	-0.9	-0.9	-0.9	-1.0	-1.4	-1.1
Arusha	14.2	5.9	5.9	6.0	6.0	5.8	5.9	6.0	6.0
Bukoba	22.4	-0.4	-0.5	-0.6	-0.6	-0.7	-0.8	-0.6	-0.7
Dagoretti Corner	20.9	-2.2	-2.2	-2.1	-2.1	-2.2	-2.3	-2.1	-2.1
Dar es Salaam	26.6	0.5	0.5	0.6	0.5	0.5	0.4	0.5	0.5
Dodoma	23.3	-0.3	-0.3	-0.2	-0.2	-0.4	-0.5	-0.5	-0.5
Eldoret	18.9	-0.9	-1.0	-1.0	-1.0	-0.8	-0.9	-1.0	-1.0
Entebbe	23.1	-0.5	-0.6	-0.8	-0.8	-0.7	-0.7	-1.2	-1.0
Garissa	29.7	0.8	0.8	0.5	0.6	0.5	0.5	0.7	0.8
Gulu	25.0	-0.7	-0.8	-0.9	-0.9	-0.9	-0.9	-1.6	-1.1
Jinja	22.2	0.8	0.8	0.7	0.7	0.9	1.0	0.4	0.5
Kabale	18.3	-0.4	-0.4	-0.5	-0.6	-0.5	-0.5	-0.6	-0.7
Kasese	24.5	-0.5	-0.6	-0.7	-0.7	0.0	0.1	-0.8	-0.8
Kigoma	23.9	0.6	0.5	0.4	0.5	0.4	0.4	0.4	0.3
Kisumu	23.9	-0.4	-0.4	-0.5	-0.4	0.4	0.4	-0.5	-0.6
Kitigum	26.1	-0.2	-0.3	-0.4	-0.4	-0.4	-0.5	-0.9	-0.6
Lamu	28.3	-0.4	-0.3	-0.4	-0.4	-0.5	-0.5	-0.4	-0.4
Lodwar	30.2	0.0	-0.1	0.0	-0.1	-0.1	-0.4	-0.2	-0.1
Makindu	24.9	-1.1	-1.1	-1.2	-1.1	-1.3	-1.2	-1.0	-1.0
Mandera	30.5	-0.1	-0.1	-0.1	-0.2	-0.3	-0.4	-0.3	-0.1
Marsabiti	25.0	-3.7	-3.7	-3.7	-3.7	-3.9	-4.1	-3.8	-3.7
Masaka	21.8	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.3	-0.2
Mansindi	24.5	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-1.5	-1.0
Mbarara	21.4	-0.3	-0.4	-0.5	-0.6	-0.3	-0.2	-0.7	-0.7
Mbeya	19.7	-1.6	-1.6	-1.7	-1.6	-1.8	-1.9	-1.9	-1.8
Mtwara	25.7	1.5	1.5	1.6	1.6	1.4	1.4	1.5	1.5
Musoma	22.7	1.1	1.0	1.0	1.0	1.1	0.9	0.9	0.8
Mwanza	23.2	0.2	0.2	0.1	0.1	0.0	-0.1	-0.1	-0.1
Namulonge	23.1	-0.4	-0.4	-0.6	-0.6	-0.5	-0.6	-1.2	-0.9
Narok	18.2	-0.4	-0.4	-0.3	-0.3	-0.4	-0.6	-0.4	-0.4
Same	24.8	-1.0	-1.0	-1.0	-1.1	-1.3	-1.1	-1.0	-1.0
Serere	25.4	-0.6	-0.7	-0.8	-0.8	-0.7	-0.7	-1.1	-1.0
Songea	22.0	-0.7	-0.7	-0.7	-0.6	-0.9	-0.9	-0.9	-0.8
Soroti	25.7	-0.6	-0.7	-0.8	-0.8	-0.7	-0.7	-1.0	-0.9
Tabora	23.2	-0.1	-0.1	-0.2	-0.1	-0.3	-0.4	-0.4	-0.3
Tororo	23.2	0.3	0.2	0.2	0.1	0.9	1.1	0.0	0.0
Voi	26.8	-0.6	-0.6	-0.7	-0.7	-0.9	-0.7	-0.6	-0.6
Wajir	29.7	-0.6	-0.7	-0.6	-0.6	-0.9	-0.9	-0.8	-0.6

Table 3. 28 Mean temperatures for August-December in 2030s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Name of location	**Baseline - Tav - ASOND (^{0}C)**	**Mean temperature change (^{0}C)**							
		2020-2049-CSIRO_rcp45	**2020-2049-CSIRO_rcp85**	**2020-2049-MIROC_rcp45**	**2020-2049-MIROC_rcp85**	**2020-2049-MRI-CGCM3_rcp45**	**2020-2049-MRI-CGCM3_rcp85**	**2020-2049-NorESM1-M_rcp45**	**2020-2049-NorESM1-M_rcp85**
Arua	23.9	-0.8	-0.9	-1.0	-0.9	-0.8	-1.1	-1.3	-1.1
Arusha	14.2	5.6	5.7	5.8	5.8	5.6	5.5	5.8	5.9
Bukoba	22.2	-0.5	-0.6	-0.6	-0.6	-0.7	-0.7	-0.7	-0.7
Dagoretti Corner	20.5	-2.4	-2.4	-2.3	-2.2	-2.5	-2.6	-2.3	-2.2
Dar es Salaam	26.6	-0.7	-0.7	-0.6	-0.6	-0.8	-0.7	-0.6	-0.5
Dodoma	23.9	-0.5	-0.5	-0.4	-0.4	-0.7	-0.7	-0.6	-0.6
Eldoret	18.0	-0.9	-0.8	-0.8	-0.8	-0.8	-0.9	-1.0	-0.9
Entebbe	22.6	-0.4	-0.5	-0.6	-0.7	-0.5	-0.5	-0.9	-0.8
Garissa	28.5	0.6	0.7	0.5	0.7	0.6	0.6	0.7	0.9
Gulu	24.1	-0.8	-0.9	-0.9	-0.9	-0.8	-1.1	-1.4	-1.2
Jinja	21.7	1.1	1.0	0.8	0.8	1.1	1.0	0.5	0.6
Kabale	18.2	-0.4	-0.5	-0.4	-0.5	-0.6	-0.7	-0.5	-0.7
Kasese	24.3	-0.9	-1.0	-0.9	-0.9	-0.2	-0.4	-1.2	-1.1
Kigoma	24.4	0.4	0.3	0.4	0.4	0.3	0.3	0.2	0.1
Kisumu	23.5	0.0	0.0	0.0	0.0	0.4	0.4	-0.2	-0.1
Kitigum	24.9	-0.4	-0.5	-0.6	-0.6	-0.6	-0.8	-1.0	-0.9
Lamu	27.4	-0.4	-0.3	-0.2	-0.2	-0.4	-0.3	-0.2	-0.1
Lodwar	29.7	0.1	0.1	0.2	0.2	-0.1	-0.2	-0.2	-0.4
Makindu	24.0	-1.5	-1.4	-1.4	-1.4	-1.4	-1.5	-1.3	-1.2
Mandera	29.2	0.1	0.0	-0.1	-0.1	-0.2	0.0	0.0	0.0
Marsabiti	24.1	-4.3	-4.2	-4.4	-4.2	-4.5	-4.5	-4.4	-4.3
Masaka	21.7	0.0	-0.1	-0.1	-0.1	0.1	0.0	-0.4	-0.3
Mansindi	23.8	-0.8	-0.9	-0.9	-0.9	-0.6	-0.8	-1.4	-1.2
Mbarara	21.2	-0.6	-0.7	-0.6	-0.6	-0.6	-0.6	-0.8	-0.9
Mbeya	20.7	-1.6	-1.6	-1.5	-1.3	-1.8	-1.8	-1.6	-1.7
Mtwara	26.9	-0.3	-0.3	-0.2	-0.1	-0.4	-0.3	-0.1	-0.1
Musoma	23.2	0.6	0.5	0.5	0.5	0.4	0.5	0.4	0.5
Mwanza	23.6	-0.3	-0.3	-0.3	-0.3	-0.5	-0.4	-0.5	-0.4
Namulonge	22.6	-0.1	-0.3	-0.5	-0.5	-0.2	-0.5	-0.9	-0.8
Narok	17.5	-0.3	-0.2	-0.2	-0.1	-0.4	-0.4	-0.3	-0.1
Same	24.5	-1.6	-1.5	-1.5	-1.5	-1.6	-1.6	-1.4	-1.3
Serere	24.6	-0.3	-0.4	-0.4	-0.4	-0.2	-0.4	-0.7	-0.6
Songea	23.1	-1.0	-1.0	-0.9	-0.7	-1.1	-1.1	-1.0	-1.1
Soroti	25.0	-0.5	-0.6	-0.6	-0.6	-0.5	-0.7	-0.9	-0.9
Tabora	24.8	-0.2	-0.2	-0.1	-0.1	-0.4	-0.4	-0.3	-0.3
Tororo	22.6	0.3	0.2	0.3	0.2	0.7	0.7	0.0	0.0
Voi	25.9	-1.2	-1.2	-1.	-1.2	-1.3	-1.2	-1.1	-1.0

Table 3. 29 Mean temperatures for August-December in 2050s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Name of location	**Baseline - Tav - ASOND (^{0}C)**	**Mean temperature change (^{0}C)**							
		2040-2069-CSIRO_rcp45	**2040-2069-CSIRO_rcp85**	**2040-2069-MIROC_rcp45**	**2040-2069-MIROC_rcp85**	**2040-2069-MRI-CGCM3_rcp45**	**2040-2069-MRI-CGCM3_rcp85**	**2040-2069-NorESM1-M_rcp45**	**2040-2069-NorESM1-M_rcp85**
Arua	23.9	-0.8	-0.9	-0.9	-0.9	-0.7	-1.0	-1.2	-1.1
Arusha	14.2	5.8	5.8	5.9	6.0	5.7	5.7	5.9	6.0
Bukoba	22.2	-0.4	-0.5	-0.5	-0.5	-0.6	-0.6	-0.6	-0.6
Dagoretti Corner	20.5	-2.3	-2.2	-2.2	-2.1	-2.3	-2.4	-2.2	-2.0
Dar es Salaam	26.6	-0.6	-0.6	-0.5	-0.5	-0.7	-0.6	-0.5	-0.4
Dodoma	23.9	-0.3	-0.3	-0.2	-0.1	-0.5	-0.5	-0.4	-0.4
Eldoret	18.0	-0.9	-0.9	-0.8	-0.8	-0.8	-0.9	-1.0	-0.9
Entebbe	22.6	-0.4	-0.5	-0.5	-0.5	-0.4	-0.4	-0.8	-0.7
Garissa	28.5	0.8	0.8	0.7	0.9	0.7	0.8	0.8	1.1
Gulu	24.1	-0.7	-0.8	-0.9	-0.8	-0.8	-1.0	-1.3	-1.1
Jinja	21.7	1.2	1.1	1.0	0.9	1.2	1.1	0.7	0.7
Kabale	18.2	-0.2	-0.2	-0.2	-0.3	-0.4	-0.4	-0.4	-0.5
Kasese	24.3	-0.9	-0.9	-0.8	-0.8	-0.2	-0.3	-1.1	-1.1
Kigoma	24.4	0.6	0.5	0.6	0.5	0.5	0.5	0.4	0.3
Kisumu	23.5	0.1	0.1	0.2	0.1	0.5	0.5	0.0	0.0
Kitigum	24.9	-0.4	-0.6	-0.6	-0.6	-0.6	-0.8	-1.0	-0.8
Lamu	27.4	-0.4	-0.3	-0.2	-0.2	-0.4	-0.3	-0.2	-0.2
Lodwar	29.7	0.1	0.1	0.3	0.3	-0.1	-0.2	-0.2	-0.2
Makindu	24.0	-1.2	-1.2	-1.2	-1.1	-1.2	-1.2	-1.1	-1.0
Mandera	29.2	0.2	0.1	0.0	0.1	-0.1	0.1	0.1	0.1
Marsabiti	24.1	-4.2	-4.1	-4.2	-4.0	-4.3	-4.4	-4.3	-4.1
Masaka	21.7	0.1	0.0	0.0	0.0	0.2	0.2	-0.2	-0.1
Mansindi	23.8	-0.7	-0.8	-0.9	-0.8	-0.6	-0.7	-1.4	-1.1
Mbarara	21.2	-0.5	-0.6	-0.4	-0.5	-0.3	-0.4	-0.6	-0.7
Mbeya	20.7	-1.3	-1.4	-1.3	-1.1	-1.5	-1.6	-1.4	-1.4
Mtwara	26.9	-0.1	-0.1	0.0	0.0	-0.2	-0.2	0.0	0.0
Musoma	23.2	0.7	0.6	0.7	0.6	0.6	0.6	0.5	0.6
Mwanza	23.6	-0.1	-0.1	-0.1	-0.1	-0.3	-0.3	-0.3	-0.2
Namulonge	22.6	0.0	-0.2	-0.3	-0.4	-0.1	-0.3	-0.7	-0.6
Narok	17.5	-0.1	-0.1	0.0	0.0	-0.2	-0.3	-0.1	0.0
Same	24.5	-1.4	-1.3	-1.3	-1.3	-1.4	-1.4	-1.2	-1.1
Serere	24.6	-0.3	-0.4	-0.4	-0.4	-0.3	-0.4	-0.8	-0.6
Songea	23.1	-0.8	-0.8	-0.7	-0.5	-0.9	-0.9	-0.8	-0.9
Soroti	25.0	-0.5	-0.6	-0.6	-0.6	-0.5	-0.7	-1.0	-0.8
Tabora	24.8	0.0	0.0	0.1	0.1	-0.2	-0.2	-0.1	-0.1
Tororo	22.6	0.3	0.2	0.4	0.3	0.8	0.7	0.1	0.1
Voi	25.9	-1.0	-1.0	-1.0	-1.0	-1.1	-1.0	-0.9	-0.8
Wajir	28.4	-0.5	-0.5	-0.6	-0.5	-0.7	-0.7	-0.6	-0.4

Table 3. 30 Mean temperatures for August-December in 2070s for the 4 GCMs under two representative concentration pathways, RCP4.5 and RCP 8.5

Name of location	**Baseline - Tav - ASOND (^{0}C)**	**Mean temperature change (^{0}C)**							
		2060-2089-CSIRO_rcp45	**2060-2089-CSIRO_rcp85**	**2060-2089-MIROC_rcp45**	**2060-2089-MIROC_rcp85**	**2060-2089-MRI-CGCM3_rcp45**	**2060-2089-MRI-CGCM3_rcp85**	**2060-2089-NorESM1-M_rcp45**	**2060-2089-NorESM1-M_rcp85**
Arua	23.9	-0.7	-0.8	-0.8	-0.7	-0.6	-0.9	-1.1	-0.9
Arusha	14.2	5.6	5.6	5.8	5.8	5.6	5.5	5.8	5.8
Bukoba	22.2	-0.6	-0.7	-0.6	-0.7	-0.8	-0.8	-0.7	-0.7
Dagoretti Corner	20.5	-2.5	-2.5	-2.4	-2.3	-2.5	-2.6	-2.4	-2.3
Dar es Salaam	26.6	-0.7	-0.7	-0.6	-0.6	-0.8	-0.7	-0.6	-0.6
Dodoma	23.9	-0.5	-0.5	-0.4	-0.2	-0.6	-0.6	-0.5	-0.5
Eldoret	18.0	-0.9	-0.9	-0.8	-0.8	-0.9	-0.9	-1.1	-1.0
Entebbe	22.6	-0.5	-0.6	-0.7	-0.7	-0.6	-0.6	-1.0	-0.9
Garissa	28.5	0.7	0.8	0.8	0.9	0.8	0.7	0.8	1.0
Gulu	24.1	-0.7	-0.8	-0.8	-0.8	-0.8	-1.0	-1.3	-1.0
Jinja	21.7	1.0	0.9	0.9	1.0	1.0	1.0	0.6	0.8
Kabale	18.2	-0.3	-0.4	-0.3	-0.3	-0.5	-0.6	-0.3	-0.5
Kasese	24.3	-0.7	-0.8	-0.8	-0.8	-0.2	-0.2	-1.0	-1.1
Kigoma	24.4	0.5	0.4	0.5	0.4	0.4	0.4	0.3	0.2
Kisumu	23.5	-0.1	-0.1	-0.1	0.0	0.3	0.3	-0.3	-0.2
Kitigum	24.9	-0.5	-0.6	-0.6	-0.6	-0.6	-0.8	-1.0	-0.8
Lamu	27.4	-0.4	-0.4	-0.3	-0.3	-0.5	-0.4	-0.3	-0.2
Lodwar	29.7	-0.1	-0.1	0.1	0.2	-0.3	-0.3	-0.3	-0.1
Makindu	24.0	-1.3	-1.2	-1.2	-1.1	-1.3	-1.3	-1.1	-1.0
Mandera	29.2	0.0	0.0	-0.1	-0.1	-0.2	-0.1	-0.1	0.0
Marsabiti	24.1	-4.2	-4.2	-4.3	-4.1	-4.4	-4.4	-4.3	-4.2
Masaka	21.7	-0.1	-0.2	-0.1	-0.2	0.0	0.0	-0.3	-0.2
Mansindi	23.8	-0.7	-0.8	-0.7	-0.7	-0.6	-0.7	-1.2	-1.0
Mbarara	21.2	-0.4	-0.5	-0.4	-0.4	-0.3	-0.3	-0.6	-0.6
Mbeya	20.7	-1.4	-1.5	-1.4	-1.2	-1.6	-1.7	-1.5	-1.5
Mtwara	26.9	-0.2	-0.2	-0.1	-0.1	-0.3	-0.3	0.0	0.0
Musoma	23.2	0.6	0.5	0.6	0.6	0.4	0.5	0.5	0.5
Mwanza	23.6	-0.2	-0.2	-0.2	-0.2	-0.4	-0.4	-0.4	-0.3
Namulonge	22.6	-0.2	-0.3	-0.3	-0.3	-0.2	-0.2	-0.7	-0.5
Narok	17.5	-0.3	-0.3	-0.2	-0.1	-0.3	-0.5	-0.3	-0.2
Same	24.5	-1.5	-1.4	-1.4	-1.4	-1.6	-1.6	-1.3	-1.2
Serere	24.6	-0.3	-0.4	-0.4	-0.4	-0.4	-0.5	-0.8	-0.7
Songea	23.1	-0.9	-1.0	-0.8	-0.7	-1.0	-1.1	-0.9	-1.0
Soroti	25.0	-0.5	-0.6	-0.6	-0.6	-0.7	-0.7	-1.0	-0.9
Tabora	24.8	-0.1	-0.1	0.0	0.0	-0.2	-0.2	-0.1	-0.1
Tororo	22.6	0.2	0.1	0.2	0.1	0.6	0.6	-0.1	0.0
Voi	25.9	-1.1	-1.1	-1.0	-1.1	-1.1	-1.1	-1.0	-0.9
Wajir	28.4	-0.6	-0.6	-0.7	0.5	-0.8	-0.8	-0.7	-0.5

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