VULNERABILITY, IMPACTS AND ADAPTATION ASSESSMENT IN THE EAST AFRICA REGION

CHAPTER 8: AGRICULTURE AND FOOD SECURITY – FUTURE IMPACTS FROM CLIMATE CHANGE

NOVEMBER 2017

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CONTENTS

ACRONYMS

AIC	Akaike Information Criterion
ANPP	Annual Net Primary Productivity
ARDS	Agricultural Rural Development Strategy
CAADP	Comprehensive Africa Agriculture Development Programme
CCAFS	Climate Change, Agriculture and Food Security
CCU	Climate Change Unit
CGIAR	Consultative Group on International Agricultural Research
DOM	Department of Meteorology
EAC	East African Community
EUS	Epizootic ulcerative syndrome
FAO	Food and Agriculture Organization
FSAP	Food Security Action Plan
GCM	Global climate model
GDP	Gross domestic product
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
JJAS	June-July-August-September
LVB	Lake Victoria Basin
MA	Moving average
MAM	March-April-May
MAXENT	Maximum entropy
ML	Maximum likelihood
NAPA	National Adaptation Program for Action
NCCRS	National Climate Change Response Strategy
NMA	National Meteorological Authority
OND	October-November-December
RCP	Representative Concentration Pathway
RVF	Rift Valley Fever
USAID	United States Agency for International Development
VIA	Vulnerability, Impacts and Adaptation Assessment

1.0 IMPORTANCE OF AGRICULTURE IN EAST AFRICA

1.1 AGRICULTURE AND FOOD SECURITY

All five East African countries (Burundi, Kenya, Rwanda, Tanzania, and Uganda) can be characterized as "agriculture-based," that is, agriculture is the backbone of these economies. Agriculture is dominated by smallholder farmers who occupy most of land and produce for household income and food security.

A majority of the agricultural production in East Africa is rain-fed (90–95 percent) making its productivity highly sensitive to climate variability and change. Irrigated agriculture accounts for about 5–10 percent of agricultural production. This can be attributed to low investment in the development of irrigation infrastructure, though the region has a good network of water resources.

An estimated 25–60 percent of the region's population is undernourished, with almost 10 percent living under chronic food insecurity conditions in the past decade, due to both increasing climatic shocks and non-climatic stressors, such as escalating food prices, natural resources-–based conflicts, high poverty rates, rapidly increasing population, and high post-harvest losses.

Despite all these challenges agriculture is still an important economic driver for sustainable development in East African Community (EAC) and employs about 80 percent of its rural population. The sector contributes to food security, foreign exchange earnings, and provides raw materials for agro-based industries (Table 1).

Table 1: Economic importance of agriculture in East Africa

	Tanzania	Kenya	Uganda	Rwanda	Burundi
Agriculture GDP	27%	29%	23.8%	36%	50%
Crops to GDP	34.8%	66%	45%	30.3%	70%
Forex contribution	35%	60%		45%	90.2%
Employment	77.5%	80%	80%	86.5%	90%
Food crops	Maize, sorghum, millet, cassava, sweet potatoes, bananas, pulses, paddy, and wheat	Maize, wheat, beans, peas, and potatoes	Plantains, cassava, sweet potatoes, millet, sorghum, maize, beans, and groundnuts	Plantains, sweet potato, pulses, Irish potato, paddy, maize	Banana, roots/tubers, pulses, paddy, wheat, groundnuts
Export crops	Coffee, cashew nut, tea, cotton, tobacco, and sisal	Coffee, tea, horticultural crops	Coffee, cotton, tea, cocoa, tobacco, sugar cane, flowers, and horticulture	Horticulture, tea, and coffee	Coffee, tea, cotton, oil palm

	Tanzania	Kenya	Uganda	Rwanda	Burundi
Reference	Arndt et al. 2012, Paul and Thurlow 2011	Asfaw et al. 2009, Minot and Ngigi 2004	Diao et al. 2010, Walaga and Hauser 2005	Diao et al. 2010, Diop et al. 2005, Nabahungu and Visser 2011	Diao et al. 2007, Nkurunzinza et al. 2012

Food security has been defined many ways and debate about the matter continues. However, the Food and Agriculture Organisation (FAO) has indicated that food security is met when "all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). The effects of increased climate variability and change are inhibiting the efficient operation of food production systems and thus the achievement of sustainable food security, especially in Sub-Saharan Africa.

Achieving sustainable food security in East Africa with a growing population, changing diets, and changing climatic conditions is a major challenge. More food is needed in the future but increased climate variability and change means less food production potential and resource-poor people will be hit the hardest. Climate-related crop failures, fishery collapses, and livestock deaths already cause economic losses and undermine food security, and these are likely to become more severe as global warming continues (CCAFS 2014).

Crop productivity in the region is low and substantially below global average levels. This is because production is dominated by smallholder farmers (about 60 percent) who are constrained by limited access to quality inputs and markets, limited access to credit, low agricultural production skill levels, low use of appropriate production technologies, as well as high food and energy costs. Some important aspects of the sector in the East African region are highlighted in Box 1.

Box 1: Key aspects of agricultural productivity in East Africa

- Low crop productivity is evident in the average growth rate in maize production: about 1.1 percent. While at the global level, maize yields stand at 4.9 tons per hectare, yields in the EAC are highly variable and average about 1.6 tons per hectare annually.
- Rice productivity, meanwhile, has been growing, with regional average yields of about 2.0 tons per heactare over 1965–2010.
- Dry bean productivity is generally low and stagnating in the EAC, currently averaging 2 tons per hectare.
- Cassava production in the EAC rose from about 5.4 tons per hectare in the 1960s to a high of 10.3 tons per hectare in the mid-1980s and now is 8.3 tons per hectare.
- Meanwhile, sorghum is at an average of 1 ton per hectare, up from 0.9 tons per hectare over 1965–1970.
- Though the East African region contributes 28 percent of the world market tea supply, its overall productivity is still low due to high production cost and other underlying economic factors.
- The regional livestock resource base is estimated to consist of 50.2 million head of cattle, 59.6 million goats, 25.3 million sheep, 6.3 million pigs, 109.8 million poultry, and 0.9 million camels. The productivity of livestock and livestock products also remains lower than global

averages, and is constrained by, among other things, increased climate variability and change leading to water and pasture scarcity.

- Average milk productivity in the EAC was 340 kilograms per animal during the period 1965–2010 and increased to 410 kilograms per animal during the period 2005–2010. However, this is below global productivity of 2,197 kilograms per animal per year.
- Fisheries and Aquaculture in East Africa has great potential for expansion. Whereas capture fisheries are dominated by the Nile perch and the pelagics, aquaculture production in the Lake Victoria Basin (LVB) is based on two main species: catfish (*Clariasgariepinus*) and the Nile tilapia (*Oreochromis niloticus*). The total aquaculture production from LVB is estimated to be around 100,000 tons, 50 percent of which comes from Uganda.

Climate data show that East Africa is getting warmer and drier, by between +0.9°C and +1.2°C, while rainfall is declining at an average rate of 20–100 millimeters every 10 years. This is coupled with high inter-seasonal rainfall variability, especially in marginal agricultural areas. These trends are resulting in the reduction of arable land areas suitable for staple food production, shifts in agro-ecological zones, decline in agricultural productivity and increase in natural resource conflicts, hence negatively affecting livelihoods. There is also an increase in the frequency and intensity of extreme weather events (3–5 years cycles), such as droughts, floods, strong winds, and hailstorms, limiting the ability of vulnerable households to recover from such climatic shocks.

Other critical non-climatic drivers also affect agriculture in East Africa, especially in the LVB:

- Poverty levels are high and agricultural production is low. The LVB is marked by negative trends for living conditions, the environment, and natural resources. Its smallholder farmers have low adaptive capacity and are highly vulnerable to increased climate variability and change. The impacts of climate variability and change are likely to be compounded by existing development challenges such as high population growth rates, high and increasing poverty levels, low per capita incomes, high levels of inequality, and declining GDP growth rates. Climate change impacts have the potential to undermine and even undo significant gains in social and economic development in East Africa.
- Population pressure is one of the main drivers of change in the LVB, especially its increasing size, rapid growth rate, and increasing urbanization and immigration. In the riverine and wetland ecosystems the main threats are reclamation for agriculture, overgrazing, pollution (from agricultural and industrial sources), siltation, human settlement and encroachment, introduction of exotic species such as blue gum trees (*Eucalyptus* spp.), and overharvesting of water-dependent plants. The degree of threat varies from one country to another.
- Since not all communities are equally endowed with environmental and social assets, vulnerability differs between regions, countries, and socioeconomic groups. Any shock in the livelihood system has the potential of setting their economic development back for several years. The indirect economic impacts of climate-related shocks can be substantial for poverty alleviation and sustainable development. Apart from the climatic factors driving vulnerability to impacts of climate change, other non-climatic factors exacerbate the vulnerability. The non-climatic factors can be grouped into technological, economic, socioeconomic, and political themes.

Long-term food productivity is threatened by degradation of natural resources especially soils. Soil degradation is severe enough to reduce yields on cropland and pastures in Africa. Sub-Saharan Africa has the highest rate of land degradation in the world. It is estimated that losses in productivity of cropping land in Sub-Saharan Africa are in the order of 0.5–1 percent annually, suggesting productivity loss of at least 20 percent over the past 40 years.

2.0 IMPACTS ON CLIMATE CHANGE AND THE HEALTH SECTOR

2.1 FOOD SECURITY

Climate change affects all four dimensions of food security and nutrition:

- **Food availability:** Changes in climatic conditions have already affected the production of some staple crops, and future climate change threatens to exacerbate this. Higher temperatures will affect yields, while changes in rainfall could affect both crop quality and quantity.
- **Food access:** Climate change could increase the prices of major crops in some regions. For the most vulnerable people, lower agricultural output means lower incomes. Under these conditions, the poorest people, who already use most of their income on food, have to sacrifice additional income and other assets to meet their nutritional requirements, or resort to poor coping strategies.
- **Food utilization:** Climate-related risks affect calorie intake, particularly in areas where chronic food insecurity is already a significant problem. Changing climatic conditions could also create a vicious cycle of disease and hunger. Nutrition is likely to be affected by climate change through related impacts on food security, dietary diversity, care practices, and health.
- **Food stability:** More intense weather events create variations in food availability, access and utilization, which negatively affect the stability of food security on the household and government level.

Climate change is affecting and will continue to affect the four dimensions of food security (FAO 2011).

Food **availability** in the region may be affected through reduced production, lack of storage, inefficient processing and distribution, and limited exchange (intra-household, and regional and global trade).

Food **accessibility**, which depends both on market and non-market distribution mechanisms, is also at risk. The capacity of individuals and households to buy food may be significantly reduced as income for farmers in East African countries depends mostly on the capacity to sell surplus production, climate change that affects the availability of certain food products will also change the prices they can charge.

Small-scale farmers, who are often not protected by social safety nets (such as insurance schemes), will remain victims to changes in market prices. If prices are too low, farmers will generate low income, if too high, farmers may be not able to sell their products (either because there are no buyers or because they themselves are not able to buy other food and so keep the surplus for their own consumption). The average effect on crop prices is variable depending on commodity, magnitude of the impact and community. But for some crops in some regions prices do not change significantly, while in others the increase is over 60 percent (Figure 1).

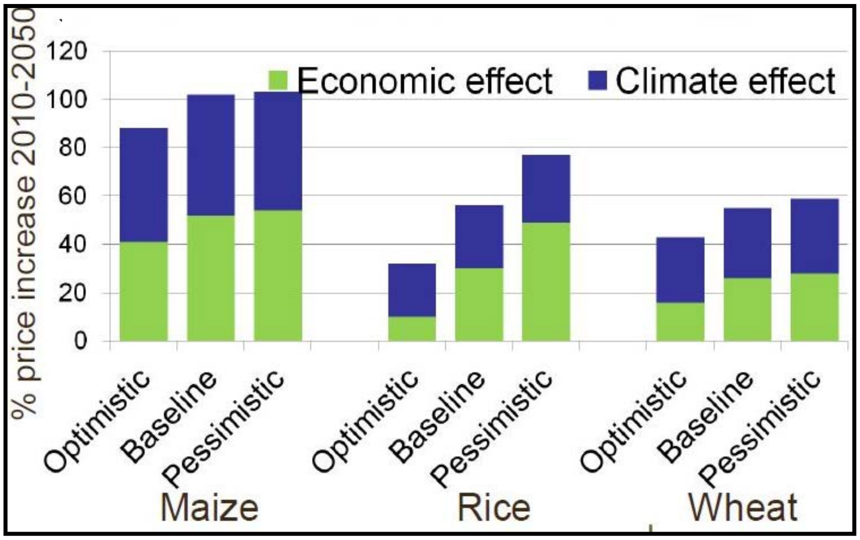

Figure 1: Impact of climate change on volatility of price of various food commodities (source: IFPRI 2013)

Food **utilization** will be mainly affected by the effects of climate change on availability and accessibility. Low income translates into the inability of households to diversify their diets, more often generating situations of chronic malnutrition (Figure 2). Food quality may deteriorate due to increased temperatures and lack of proper storage facilities, and water scarcity will also generate health hazards.

Food **stability** will be more difficult to achieve as vulnerability to drought and floods may bring chronic or periodic food insecurity. Guaranteeing the stability of food supplies will be affected by the changing patterns in crops cycles that will be impacted by climate variability (changes in temperatures and rainfalls).

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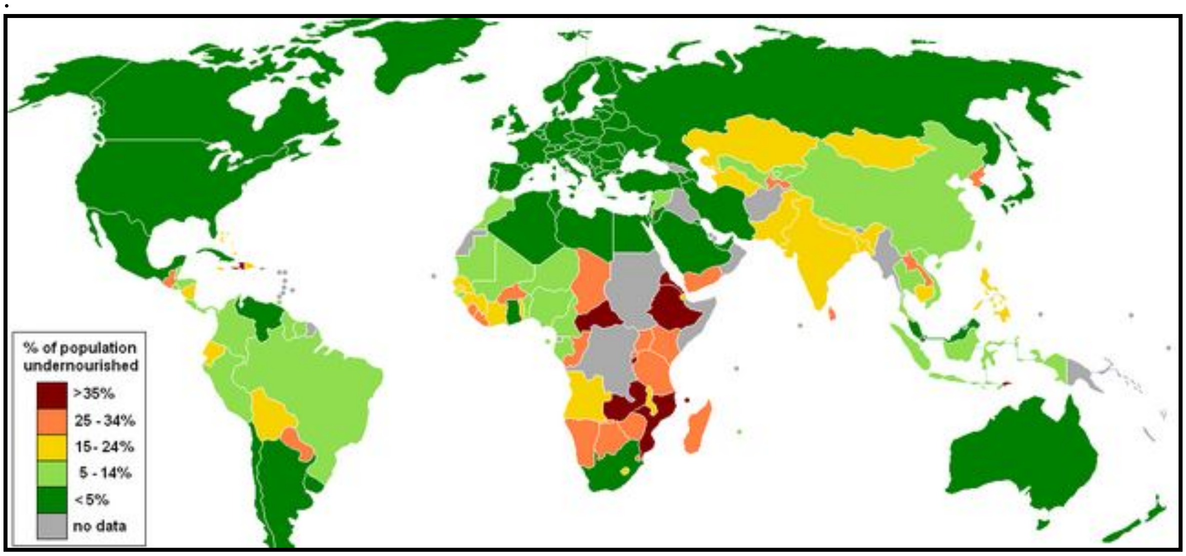


Figure 2: Differential global food utilization (source: WWF 2008)

Box 2 summarizes the role of climate change and other stressors on food security.

Box 2: Food insecurity: the role of climate variability, change, and other stressors

- The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) shows that if East Africa does not address climate change, by the 2080s, suitable rain-fed land will decrease and production potential for cereals will decline. Furthermore, the area of arid and semi-arid land in East Africa could increase by 5–8 percent.
- The study shows that wheat production is likely to disappear from East Africa by the 2080s. In other scenarios, additional risks that could be exacerbated by climate change include greater erosion, deficiencies in yields from rain-fed agriculture of up to 50 percent during the 2000–2020 period, and reductions in crop growth period. Other agricultural activities could also be affected by climate change and variability, including changes in the onset of rain days and the variability of dry spells.
- A recent study on South African agricultural impacts, based on three scenarios, indicates that crop net revenues will likely fall by as much as 90 percent by 2100, with small-scale farmers being the most severely affected. However, it is possible for adaptation to reduce these negative effects. In Egypt, for example, climate change could decrease national production of many crops (ranging from –11 percent for rice to –28 percent for soybeans) by 2050 compared with their production under current climate conditions.

Source: IPCC (2007), Fourth Assessment Report.

2.2 Agricultural Production Systems

This review synthesizes and evaluates impacts of climate on both production and non-production elements of agriculture and their adaptation to climate change (Figure 3) in the East African region with emphasis on the LVB. Crops, livestock, and aquaculture production systems within the region guide the review.

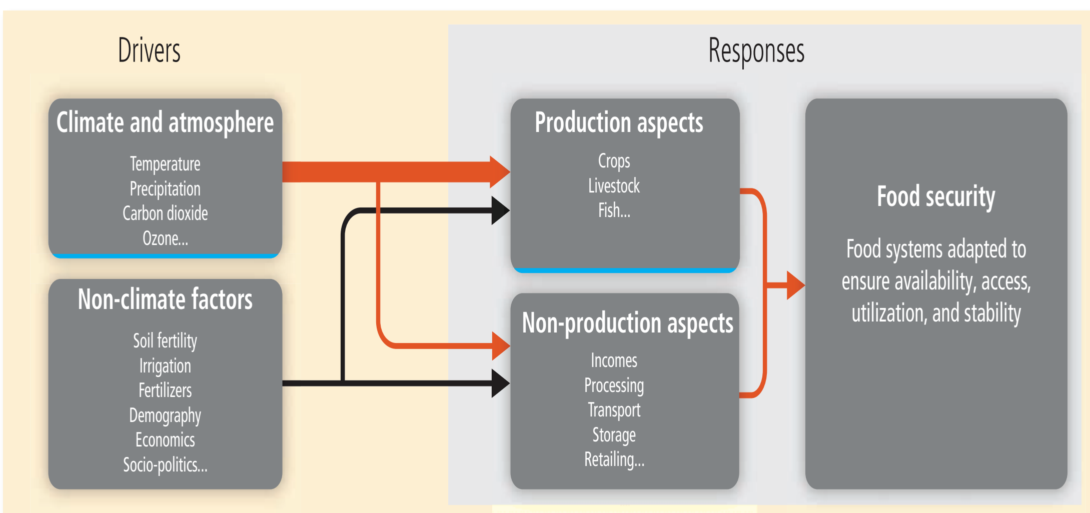


Figure 3: Framework on food security and agriculture production systems (adopted from Porter et al. 2014)

Climate change is already affecting the Earth's temperature, precipitation, and hydrological cycles (Halford and Foyer 2015). Among the impacts are the following:

- The changing hydrologic cycle is leading to more frequent and intense droughts and floods with severe effects on agricultural systems and production.
- The Earth is warming and over the next 30–50 years, average temperatures will likely increase by at least 1.0°C (Figure 4). Temperatures are expected to increase over the present limits at a variable rate, while water demand of the crops will also increase due to increased transpiration and evaporation. In the long run, rising temperature will have detrimental effects on crop production as well as livestock and fisheries.
- Atmospheric CO_2 is increasing as well and over the next 30–50 years, CO_2 concentrations will increase to about 450 parts per million by volume (ppmv) (Halford and Foyer 2015). The CO_2 response is expected to be higher on C3 species (wheat, rice, and soybeans), which account for more than 95 percent of world's species, than on C4 species (maize and sorghum). C3 weeds have responded well to elevated CO_2 levels, symbolizing the potential for increased weed pressure and reduced crop yields. Continued change in the frequency and intensity of precipitation, heat waves, and other extreme events will in general affect global agricultural production. On a global scale, the effect of climate change will vary depending on the type of system under exposure or location with which a particular system is exposed.

Climate change will have a major impact on agriculture (Yanda 2015). Variation of agricultural and climatic conditions stemming from global warming caused by increased greenhouse gases across the world makes the agriculture sector vulnerable to multiple impacts of climate change (Figure 4).

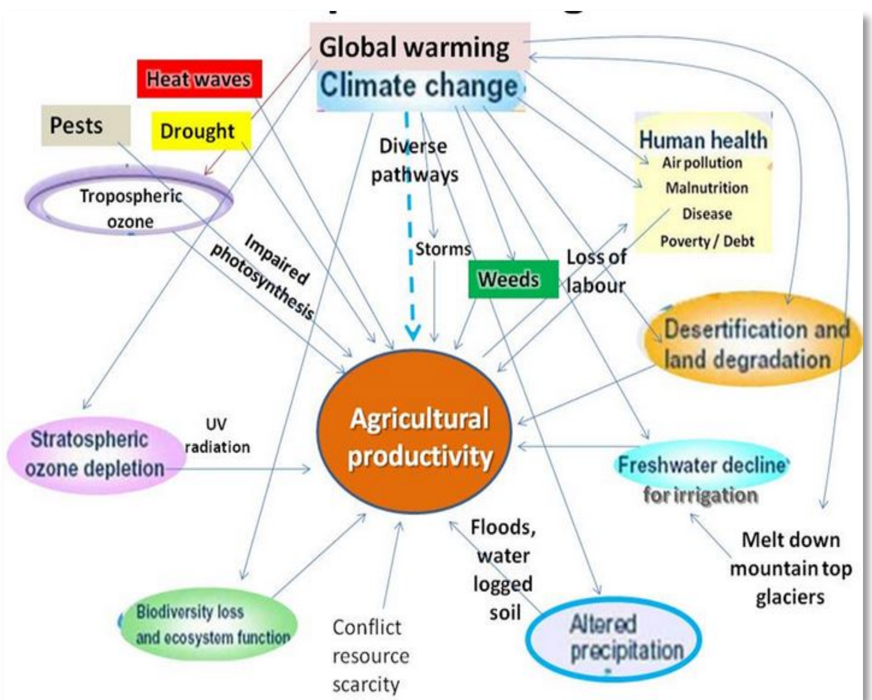


Figure 4: Multiple impacts of global warming and climate disruption in agriculture (source: Gornall et al. 2010)

Climate hazards negatively affect all actors along the agriculture value chains, but in different ways and to different extents. Along the agricultural value chain all participating actors may be vulnerable to impacts of climate hazards (mainly drought, floods, and changing rainfall patterns) on their activities. Apart from affecting agricultural commodity yields, climate hazards have been associated with disruption of the post-harvest commodity handling activities like drying processes, the destruction of inputs, and infrastructure for processing and transportation (UNCTD 2011).

Indirectly, climate hazards further contribute to reducing incomes through decreases in business activities and services provision and increased costs for business and service delivery at three levels: production (e.g., increased human labor), transformation (e.g., increased breakdown of processing equipment and machinery due to high moisture content of beans resulting from heavy rainfall), and distribution (e.g., increased vehicle repair costs due to road deterioration from heavy rainfall). As a result, a climate hazard affects commodity prices and the margins earned by the various actors with implications for the country's competitiveness on the international market (UNCTD 2011). Supply, distribution, transformation, and demand—by affecting the consumers' preferences—are all at risk due to impacts of climate change.

Under prevailing conditions East African agriculture will have bleak prospects given that crop production across the region depends overwhelmingly on rainfall (Thorn et al. 2015). Many areas are likely to have less rainfall in future and an increased incidence of droughts (see the example of Kenya; Figure 5). For instance, in 2011 there were prolonged droughts in Kenya and Tanzania. Reports show that like other countries in the Horn of Africa, Kenya has been affected by droughts almost every year for the past 12 years, with recent dreadful drought years in 2009 and 2011.

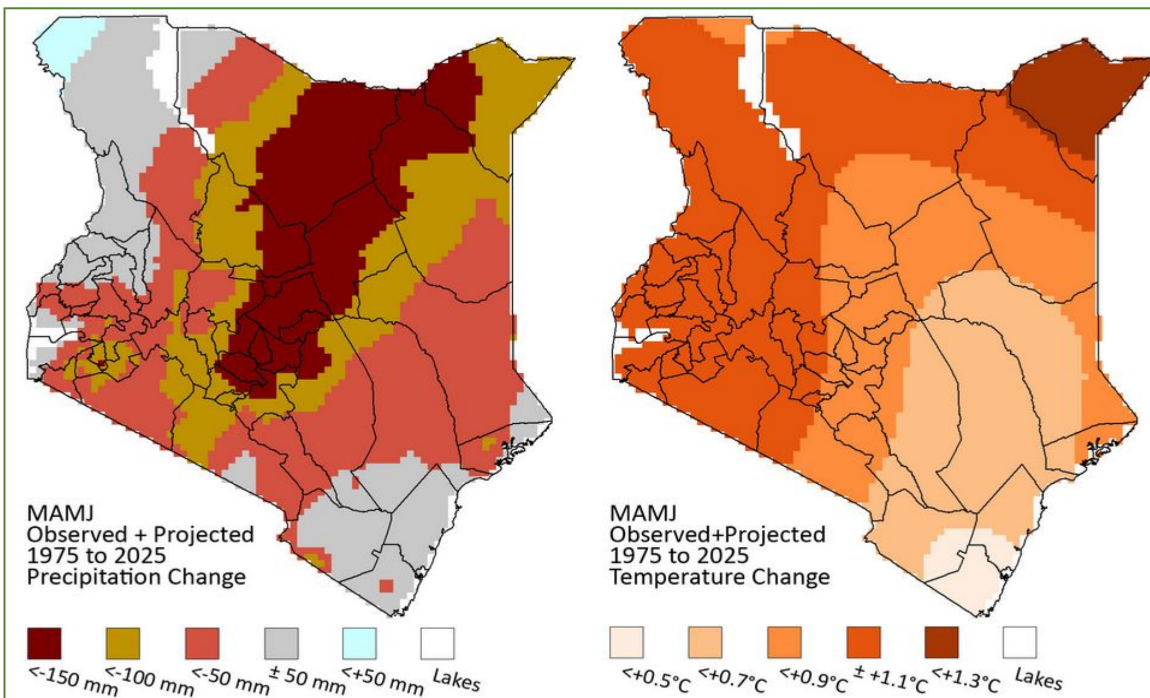


Figure 5: Observed and projected change in rainfall and temperature, together with smoothed central Kenyan rainfall (source: FEWS NET)

Climate being the driver of crop productivity, its variability and subsequent change will have implication for crop production in different parts of the region (Figure 6). Climate change impacts on crop yield are different in various areas, in some regions it will increase, in others it will decrease.

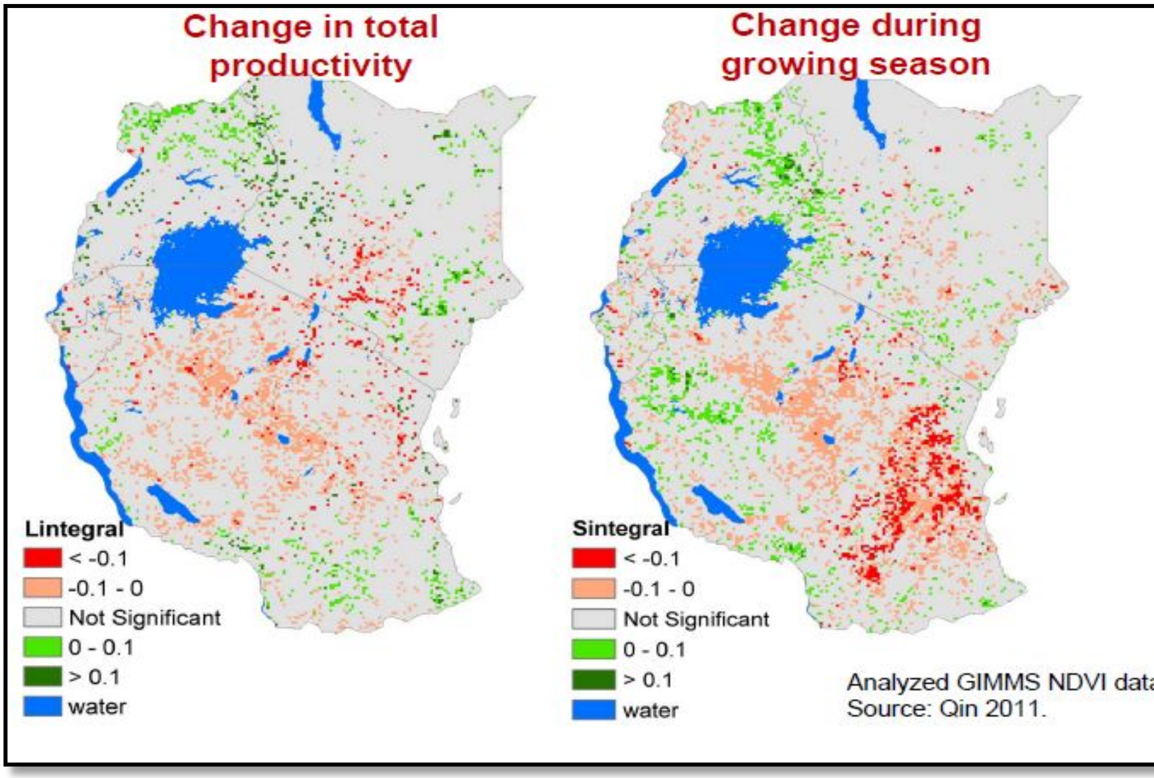


Figure 6: Trend in vegetative productivity 1982–2006 (green = increase; red = decline)

Since crop yield is more sensitive to precipitation changes than to temperature changes, it can be increased with irrigation application and precipitation increase during crop growth. If water availability is reduced in the future, soil with high water-holding capacity will be better able to reduce the frequency of drought and improve crop yield. Because of the climatic averages as well as extremes, and relationship between climate and soil characteristics, specific crops are usually localized in specific parts of the region. This creates narrow food production zones, rendering other areas food insecure. Only a fraction of the region has an average rainfall above 300 millimeters, which is the minimum threshold for most of the major crops in the region. There is also a lot of variability in the temporal and spatial distribution of rainfall, which is a common problem subjecting some areas to extremes such as floods and drought.

Climate change will lead to shifts of farming systems. Some specific studies and analysis on potential impacts of climate change on crops in East Africa are available. It is reported for Tanzania that, in the same farming system, positive and negative impacts may occur on different crops. It is suggested that impacts on maize, the main food crop, will be strongly negative for the Tanzanian smallholder, while impacts on coffee and cotton, important cash crops, may be positive (Craparo et al. 2015).

In Kenya, a 1- meter sea level rise would cause losses of almost US$500 million for three crops (mangoes, cashew nuts, and coconuts). In the tea-producing regions, a small temperature increase of 1.2°C and the resulting changes in precipitation, soil moisture, and water irrigation could render unusable large areas of land that now support tea cultivation. As Kenya is the world's second largest exporter of tea and as tea exports account for roughly 25 percent of the country's export earnings and about three million jobs (10 percent of the population), the economic impact could be tremendous (WWF 2006). Figure 7 shows how arable land can be narrowed due to variability in precipitation.

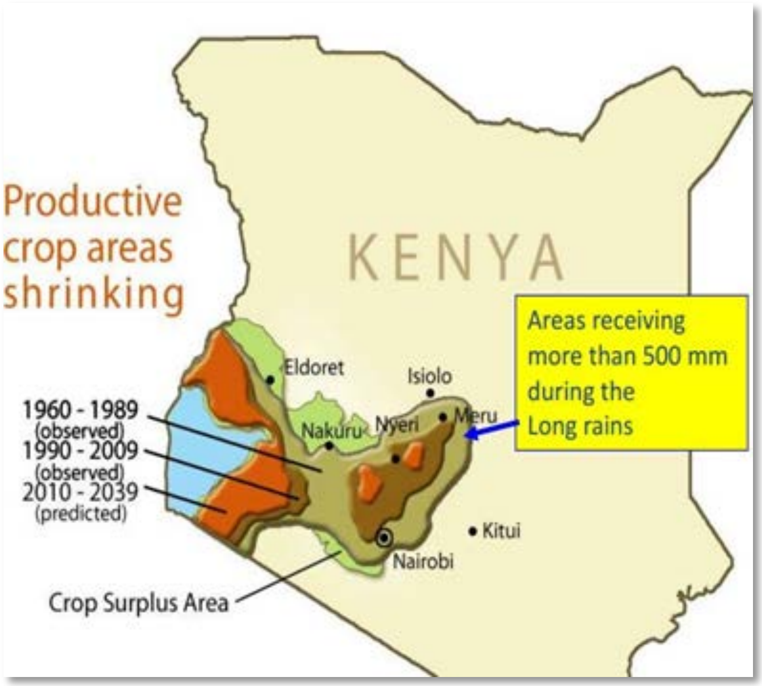


Figure 7: Average location of the 500 millimeter rainfall isohyets for the years 1975 (light brown), 1995 (dark brown), and 2025 (predicted, orange), Note: the green polygon in the background shows the main crop surplus region of Kenya (source: FEWS NET 2013)

The Ugandan National Adaptation Program for Action (NAPA) demonstrates the dramatic impact that a 2°C temperature rise might have on coffee growing (Figure 8) (Seitz and Nyangena 2009). The analysis indicates that most areas could become unsuitable for coffee growing.

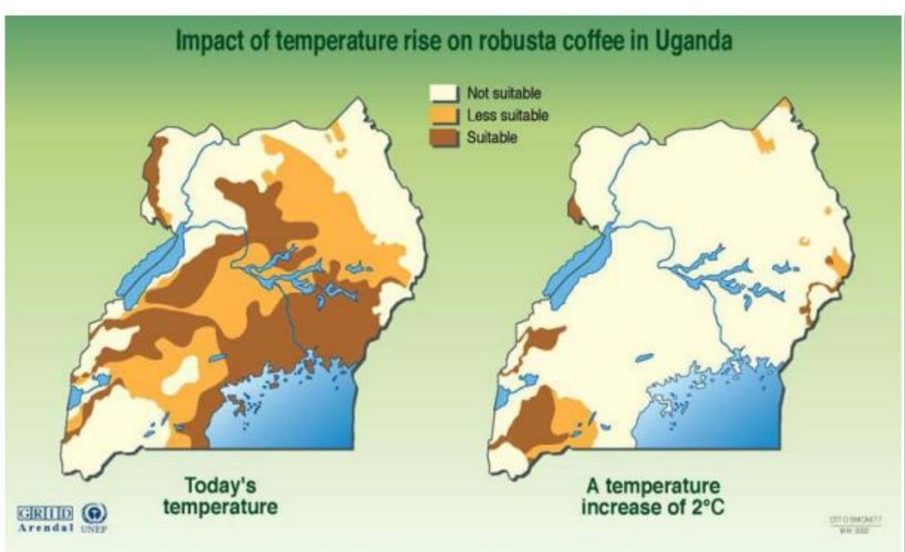


Figure 8: Impact of a 2°C temperature rise on coffee production in Uganda (source: NAPA Uganda 2007; Otto Simoneit, GRID-Geneva 1989)

Climate change and variability is likely to adversely affect seasonality, which will affect cropping patterns, and thereby affect smallholder farmers. Seasonality influences farmers' decisions about when to sow and harvest, and ultimately the success or failure of their crops due to shift of dependable cropping season. Figure 9 shows a model of shifts of cropping seasons in East Africa. These shifts make crop production more vulnerable because crop phenological parameters, such as the start and end of the growing season, the total length of the growing season, and the rate of greening and senescence are important for planning crop management, crop diversification, and intensification.

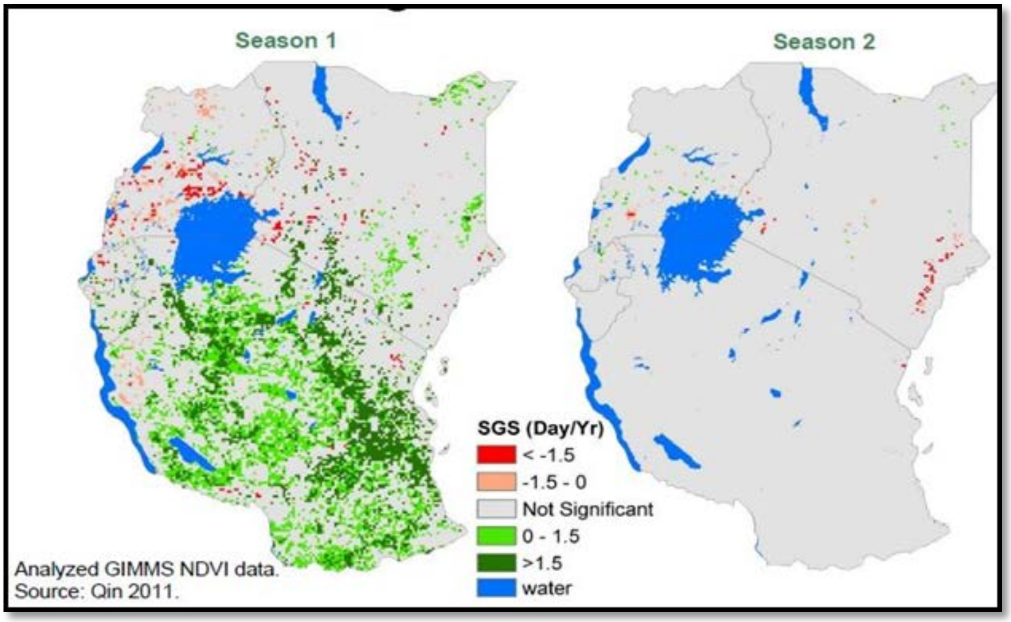


Figure 9: Change in Start of Rainy Season 1982–2006 (green = later, red = earlier)

2.3 CROPS

Rainfall and temperature regimes are perhaps the most important factors in determining the potential productivity of various agricultural enterprises either directly or indirectly.

For crops, the direct effects of rainfall and temperature determine the suitability, rate of growth, and potential yield of crops, while the indirect effects influence the supply of nutrients and water through changes in nutrient and hydrological cycles. Annual crops with short production cycles are considered much more sensitive to changes in seasonal climatic conditions compared to perennials with growth cycles covering several seasons or years. The extent to which climate change affects crop production at a given location, among others, depends on current climatic conditions at that location, type of crops grown, level of management, and status of soil and other resources.

Climate change will also affect crop production by reducing the capacity of natural resources to support productive agriculture. These include decline in soil fertility from increased mineralization, changes in soil microbe balance, reduction in plant available water due to increase in evaporative demand of the atmosphere, increase in erosion and soil degradation and changes in the distribution and incidence of pests and diseases including weeds. All these changes will have significant impact on productivity, food security, and profitability both at household and national level.

Table 2: Temperature and rainfall thresholds for the crop subsector in East Africa

- *Maize (Zea mays*). Maize is grown in temperatures of 18°C–27°C during the day and around 14°C during the night. Several studies found that temperatures above 35°C are lethal to maize pollen viability. Leaf photosynthesis rate of maize has a high optimal temperature of 33–38°C. Maize is grown mostly in regions with annual rainfall of 600–1,100 millimeters, but it is also grown in areas with rainfall of about 400 centimeters.
- *Rice (Oriza sativa*). Leaf-appearance rate increases with temperature from a base temperature of 8°C, until reaching 36°C–40°C, the thermal threshold of survival with biomass increasing up to 33°C. However, the optimal temperature for grain formation and yield is lower (25°C). High percentages of rice spikelet sterility occur if temperatures exceed 35°C at anthesis and last for more than 1 hour.
- *Sorghum (Sorghum bicola*). The vegetative development of sorghum has a base temperature of 8°C and optimal temperature of 34°C while reproductive development of sorghum has an optimal temperature of 31°C. Also reported that sorghum vegetative growth has an optimal temperature of 26°C–34°C, while reproductive growth has an optimal temperature of 25°C–28°C.
- *Common bean (Phaseolus vulgaris* L). Common bean seed yield has an optimal temperature of 23°C and a Tfp of 32°C. Studies report further that bean yield has an optimal temperature of 24°C.
- *Cassava (Manihot esculenta* Crants). Finds the most favorable growing conditions in humid-warm climates at temperatures of 25°C–29°C and precipitations of 1,000–1,500 millimeters, which ideally should be evenly distributed. Where temperature fluctuations are high, the annual average temperature must amount to 20°C. With low fluctuations in temperature, 17°C is also sufficient for successful cultivation.
- *Tea (Camellia cinensis*). The optimum temperature for tea production about 22°C. Studies have also indicated that reduction of monthly rainfall by 100 millimeters could reduce productivity by 30–80 kilograms of "made" tea per hectare. Across tea-growing areas the optimum rainfall for tea cultivation ranges from 223 to 417 millimeters per month. Depending on the elevation an increase in ambient CO_2 concentration from 370 ppm (normal) to 600 ppm, might increase tea yield by 33–37 percent due to CO_2 fertilization.
- *Coffee*. The optimum mean annual temperature range (for arabica coffee) is 18°C–21°C. Above 23°C, development and ripening of fruits are accelerated, often leading to loss of quality. Continuous exposure to temperatures as high as 30°C could result in both depressed growth and abnormalities, such as yellowing of leaves and growth of tumors at the base of the stem. A relatively high temperature during blossoming, especially if associated with a prolonged dry season, may cause abortion of flowers. The optimum annual rainfall range is 1,200–1,800 millimeters for arabica coffee. Similar range seems to be required for robusta, although it adapts better than arabica to intensive rainfall exceeding 2,000 millimeters. Abundant rainfall throughout the year is often responsible for scattered harvest and low yields. In coffee plantations subjected to large wind shears and advection, crop yield is usually depressed. Wind stress may lead to a reduction of leaf area and internode length of the orthotropic and plagiotropic branches in addition to severely damaging leaves and buds and exacerbating shedding of developing flowers and fruits.

Source: Verón et al. 2015.

Climate-related factors can affect crop yields (positively and negatively) and crop suitability through many pathways.

- First, changes in temperature and precipitation lead to changes in evaporation from the soil and transpiration from vegetation. Hence, higher temperatures will lead to increased demand for water by plants, which are difficult to meet, especially when rainfall is expected to decline and become more variable.

- Second, different crops have different optimal growing conditions and high temperatures can make the crops unsuitable for some areas where the current climatic conditions are already close to the maximum tolerable limits. Major shifts in production zones are predicted for crops with a narrow optimal temperature range such as coffee and tea.
- Third, crops grow faster and mature earlier under warmer temperatures. The available data indicate that duration of the growing season for several crops will be reduced by about one-two weeks with every degree increase in temperature, depending on current temperatures at that location and type of crop grown.
- Fourth, some crops may benefit from increased concentration of CO_2 in the atmosphere. The response of crops to increased CO_2 concentration, often referred to as "CO_2 fertilization effect," varies among plant species. Plants with a C3 photosynthetic pathway, which include potato, beans, rice, wheat, and many weed species, can benefit from this phenomenon, but no significant benefit is expected in case of crops like maize, sorghum, and millet with a C4 photosynthetic pathway. Further, attaining these benefits requires high levels of management, including use of fertilizer, optimum conditions for root growth, and control of weeds, pests, and diseases.

Given the large number of factors and their many interactions, high spatial and temporal variability in the climate, soil and other resources supporting agricultural production, and high level of uncertainty associated with future climate projections, it is extremely difficult to estimate precisely how agricultural productivity is going to be affected by changes in climate. Climate change is projected to decrease the yields of cereal crops in Africa overall through shortening growing season length, amplifying water stress, and increasing diseases, pests, and weeds (Barros et al. 2014, Vrieling et al. 2013). Among the possible environmental changes, heat and water stresses are the most important (Prasad et al. 2008).

Heat stress during crop development leads to fewer and smaller organs, reduced light interception due to shortened crop life, and altered carbon-assimilation processes including transpiration, photosynthesis, and respiration (Stone 2000). Heat stress during flowering and grain filling stages results in decreased grain count and weight, resulting in low crop yield and quality (Craita and Gerats 2013). Increase in temperature also increases the saturation vapor pressure of air, thereby increasing evaporative demand. Plants close their stomata as a response to increased evaporative demand, reducing their photosynthesis rate and increasing vulnerability to heat injury (Lobell and Gourdji 2012). Even short-duration heat shock can reduce crop yield substantially, especially if it coincides with the reproductive stage (Teixeira et al. 2013).

Water stress leads to shortening of the crop reproduction stage, reduction in leaf area, and closure of stomata to minimize water loss, reducing crop yields (Barnabás et al. 2008). Water stress also increases pollen sterility, which reduces grain yield and quality (Alqudah et al. 2011). Water stress is frequently accompanied by heat stress, as dehydration of the plant tissue leads to overheating (Lambers et al. 1998). Water and heat stresses together adversely affect plant growth and productivity, which is more pronounced than the individual impacts (Prasad et al. 2008).

In areas with excess water and heat (due to climate change) it is projected that pathogen, weed, and insect infestations will further damage agricultural systems (Ziska et al. 2011). In addition, a rise in the CO_2 level is projected to benefit C3 crops, such as wheat, rice, and soybean, while no substantial effect is expected for C4 crops such as maize, sugar cane, millet, and sorghum (Conway 2009).

Climate change affects crop production in both positive and negative ways, but negative impacts tend to dominate (Figure 10). Change in climate variables (rainfall, temperature, atmospheric CO_2, solar radiation, and wind patterns) have both direct and indirect effects on plants, soils, insects, weeds, and diseases. Climatic conditions interact with agriculture through numerous and diverse mechanisms (Yanda 2015). The mechanisms, effects, and responses include acidification of soils, survival and distribution of pest populations, effects of CO_2 concentration on photosynthate allocation to plant tissues and organs, crop breeding aims, animal shelter requirements, and the location of production.

Most plants growing in atmospheric CO_2 higher than ambient levels exhibit increased rates of photosynthesis. High CO_2 also reduces the stomatal openings of some crop plants and reduces transpiration per unit leaf area, enhancing photosynthesis. These effects may lead to improved water-use efficiency (the ratio of crop biomass to amount of water used in evapotranspiration) and therefore tend to increase growth and yield of most agricultural plants.

Although temperature rise might temporarily boost plant production, it does not do so in the long run. Some reports indicate that global warming might increase plant growth, because of higher temperatures and higher levels of atmospheric CO_2. But high atmospheric temperatures caused by elevated concentrations of CO_2 also will induce heat injury and physiological disorders in some crops, which will decrease production. The photosynthesis process is very sensitive to high temperature stress. Reproductive development is more sensitive than vegetative development to high temperatures, and heat-sensitivity differs among crops.

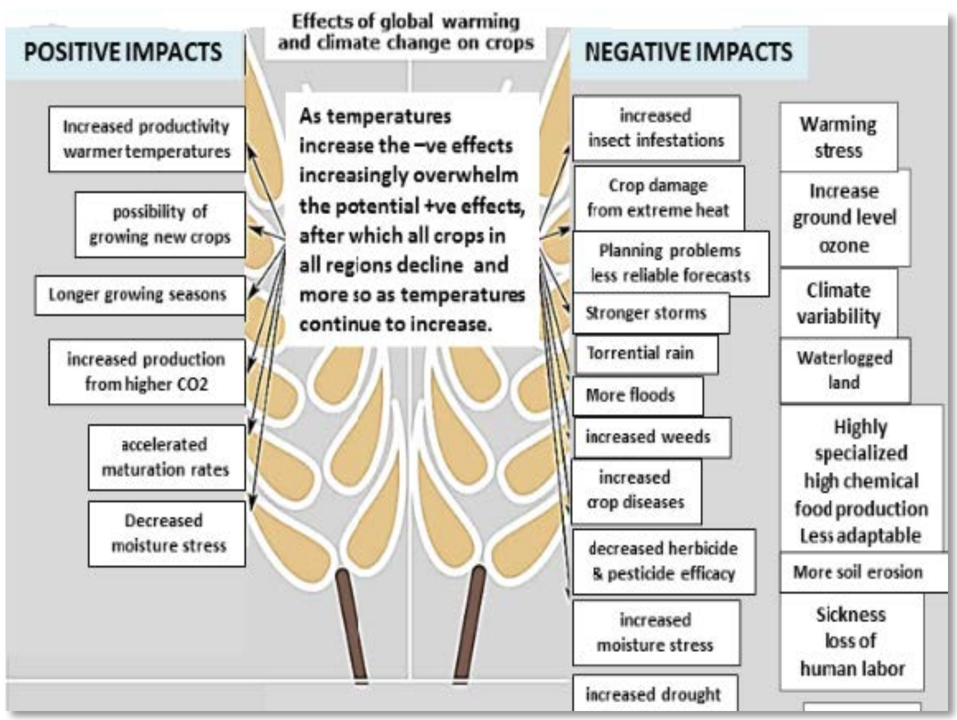


Figure 10: Positive and negative impacts of climate change on crop production (source: Gornall et al. 2010)

Adhikari et al. (2015) finds that global warming has become a major challenge in maintaining global food security. His paper reviews the impacts of climate change on 14 strategic crops for eight countries in Sub-Saharan Africa. Climate change is projected to increase median temperature by 1.4°C–5.5°C and decrease median precipitation by 2 percent to 20 percent by the end of the 21st century. However, large levels of uncertainty exist with temporal and spatial variability of rainfall. The impact of climate change on crop yields in the region is largely negative. Among the grain crops, wheat is the most vulnerable, yields may decline up to 72 percent from current levels. For other grain crops, such as maize, rice, and soybean, yield reductions of up to 45 percent are expected by the end of this century. Two grain crops, millet and sorghum, are more resilient to climate change for which projected impacts on crop yields are <20 percent. Root crops, such as sweet potato, potato, and cassava are projected to be less affected than the grain crops with declines in crop yields ranging from about 15 percent to 10 percent. For the two major export crops, tea and coffee, up to 40 percent yield loss is expected due to the reduction in suitable areas caused by temperature increase. Similar loss of suitable areas is also expected for banana and sugarcane production; however, this reduction is due to rainfall variability in lowland areas. Other crops, such as cotton and sugarcane, are projected to be more susceptible to precipitation variation that will vary significantly in the region.

To mitigate the long-term impacts of climate change on agricultural sectors, the development of small-scale irrigation systems and water harvesting structures seems promising; however, affordability of such measures remains a key issue.

Climate change will be an important driver of genetic erosion in the future. It will both threaten the survival of individual species and affect the way different elements of biodiversity interact in food and agriculture ecosystems. These interactions provide "services," such as pollination, soil fertilization, and the natural biological control of plant and animal pests and diseases that are essential for food production. Smallholder and subsistence farmers and pastoralists will be the hardest hit by disruptions in these services. This irreversible loss of biodiversity will have serious consequences for global food security. If coordinated actions are taken at the national and international levels, biodiversity can be conserved and harnessed to help food and agriculture adapt to climate change (Dinesh et al. 2015).

Rainfall availability is the most critical factor for sustaining crop productivity in rain-fed agriculture. Rainfall variability from season to season greatly affects soil water availability to crops, and thus poses crop production risks. Ideally, crop cultivations should be situated in areas with high rainfall with low variability; however, subsistence farming is done in a wide range of environmental conditions—from very suitable to marginal lands. Analysis of maize production in East Africa (using FAOSTAT crop data and long-term climatic data from GeoCLIM) showed a positive relationship with the rainfall patterns within the region. This shows the importance of rainfall variability as a climate variable and the dependence of maize production on rain-fed production (Figure 11).

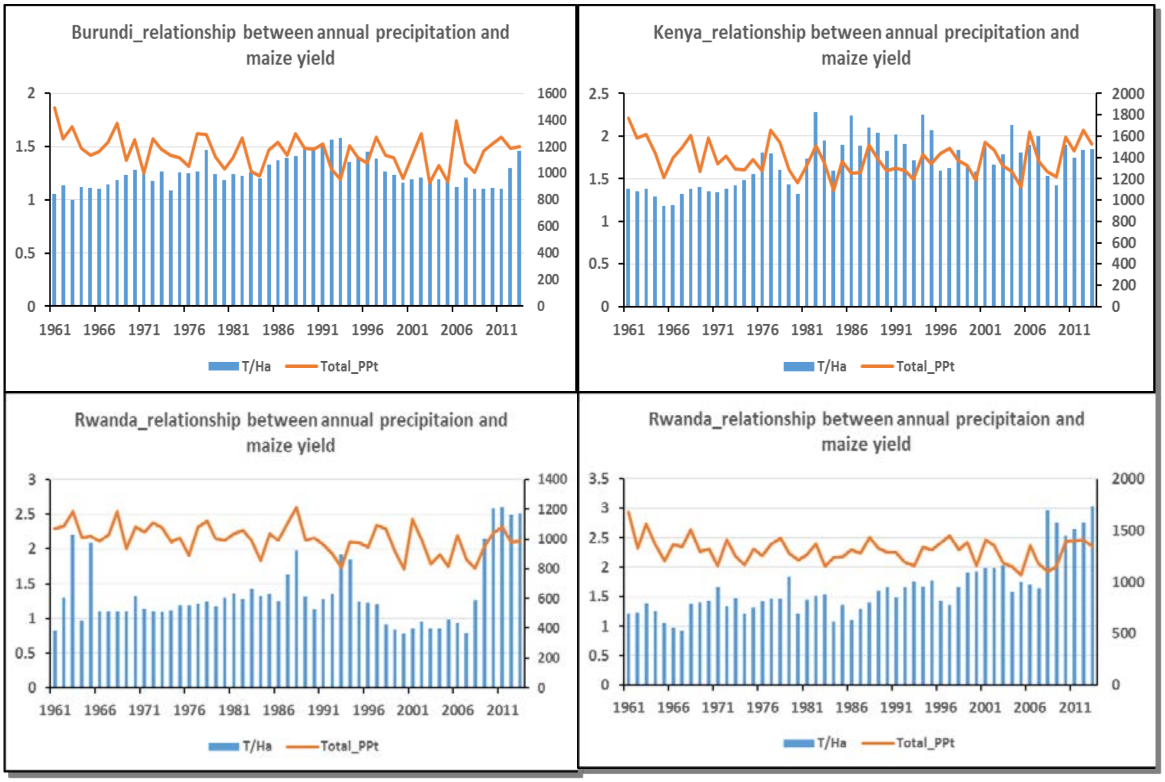


Figure 11: Relationship between annual precipitation and maize yield

Climate change may lead to major impacts from biotic stressors. Weeds are affected by climate and various atmospheric factors. Resultant changes in the geographic distribution of these crop pests and their vigor in current ranges will likely affect crops. For instance, the biomass of C4 smooth pigweed (*Amaranthus hybridus*) can increase by 240 percent for an approximate 3°C temperature increase. Accelerated range expansion of weeds into higher latitudes also is likely (Peters et al. 2014) as demonstrated for itchgrass (*Rottboellia cochinchinensis*, Lour.), cogongrass (*Imperata cylindrica*), Texas panicum (*Panicum texanum*), and witchweed (*Striga asiatica* and *S. hemotheca*) (Peters et al. 2014). However, not all exotic weeds will be favored by climatic warming. Patterson et al. (2005) found loss of competitiveness under warmer conditions for the southward spread of wild proso millet (*Panicum miliaceum*). Striga is a parasitic weed that infests approximately 158,000 hectares of arable land in the LVB. Striga cause yield loss of 30–50 percent although 100 percent is not uncommon with the value in the order of US$37–88 million per year (Cotter et al. 2012).

With regard to insect pests, stem borer (Busseola fusca) seriously limit yields by infecting the crop throughout its growth. The yield losses caused to maize vary widely and range from 20 to 40 percent in East Africa depending on the agro-ecological condition, crop cultivar, agronomic practice, and intensity of infestation (Kodjo et al. 2013). Climate is one of the abiotic factors that define ecological suitability for individual species and thus dictate composition of pest communities in different regions (Kodjo et al. 2013). Unfortunately, temperature, which is one of the important climatic variables that directly affect herbivorous insects, is predicted to increase by 1.4°C–5.8°C toward the year 2100. This change could profoundly affect population dynamics and status of cereal stem borer (Kodjo et al. 2013).

The occurrence of plant fungal and bacterial pests depends on temperature, rainfall, humidity, radiation, and dew. Climatic conditions affect the survival, growth, and spread of pathogens, as well as the resistance of hosts (Dinesh et al. 2015). Among these, mild winters have been associated with more rapid and stronger outbreaks of powdery mildew (*Erysiphe grammis*), brown leaf rust of barley (*Puccinia hordei*), and strip rust of cereals (*Puccinia striiformis*). Hence, increased climate variability associated with climate change trends may result in higher pre-harvest levels of fungal diseases and their associated mycotoxins in maize, posing both economic and health risks due to accelerated infestation of mycotoxigenic fungi of genus, *Fusarium, Aspergillus,* and *Penicillium* (Dinesh et al. 2015). A summary of climate change and crop diseases for selected crops is presented in Table 3.

The crops considered in this assessment are those most widely grown in the LVB and many are vulnerable to the projected rising temperatures and increasing dry season rainfall. Of the crops analyzed, arabica coffee is the most vulnerable, while cassava is the least. Overall, from most to least sensitive crops, they are: arabica coffee, robusta coffee, rice, maize, East African highland banana, beans, sorghum, sweet potatoes, and cassava.

Table 3: Potential impacts of climate crop disease

Crop	Potential impacts of climate and diseases
Coffee	Rising temperatures and erratic rainfall increase the risk of disease and pest infestations.
Rice	Two major diseases (blast and bacterial leaf blight) affect rice yields and are significantly aggravated by weather conditions such as higher temperatures, air humidity, or soil moisture.
Maize	Aflatoxin contamination represents a serious threat to human health and the marketing of maize and will likely worsen if dry season rainfall increases.
East African highland banana	While banana is less vulnerable to increasing temperatures than coffee, the potential impact of pests and diseases on the crop is significant.
Beans	Beans are vulnerable to fungal and viral diseases when excessive rain falls during critical growing periods.
Multiple grains	Erratic rain could increase post-harvest storage losses of crops typically dried in the sun (maize, beans, coffee, rice, etc.), due to increased pests and rotting.
Sorghum and maize	Coupled with irregular precipitation, increased temperatures could result in the proliferation of striga, a parasitic weed that affects sorghum and maize, which is prevalent in areas with degraded soils.
Sweet potatoes and cassava	Both crops grow well at temperatures much higher than current ones, but are also vulnerable to pests and disease.

Climate change will affect crop production value chains at various stages. Hence a value-chain approach needs to be considered for climate change adaptation planning. Table 4 presents a summary of the potential impacts of climate change on selected value chains.

Table 4: Possible effects of a general increase in temperature on selected aspects of post-harvest systems of crops in East Africa

Impact on post-harvest activities	Impact on rural households' post-harvest assets	Impact on human well-being outcomes
Harvesting and drying ❖ Increased rate of crop drying, in field and at homestead ❖ Increased fire risk of the mature crop **Pest & disease management** ❖ Faster reproduction of insect pests and diseases (shorter lifecycles due to higher temperatures) leading to more rapid build-up of insects and fungi in stored produce ❖ Increased risk of fungal rot and mycotoxin contamination of stored products Pest and disease territories expand to higher altitudes or previously cooler areas ❖ Efficacy decreases for some active ingredients in grain protectants and increases for others **Storing** ❖ Higher pest incidence and carry-over during "cold season" increases the need for thorough storage structure hygiene and management of residual infestation prior to storing new crop ❖ Increased pest reproduction and mobility leading to need to re-winnow, sort, and re-treat grain midway through storage period ❖ Increased moisture migration and condensation resulting in rotting zones in grain bulks with excess free	**Human** ❖ Labor productivity reduced by heat stress, reduced quality of diet and increased health risks due to more damaged produce, higher mycotoxin contamination and increased food prices ❖ Changes in post-harvest labor calendar due to faster crop drying **Natural** ❖ Crop varietal biodiversity loss if pests destroy stored grain/seed **Physical** ❖ Construction of traditional drying platforms and storage structures more difficult due to gradual loss of bio-resources **Social** ❖ Traditional food safety nets may not cope with the increased demands placed on them. ❖ Greater fluctuations in seasonal grain prices may act as an incentive for traders to store more grain **Financial** ❖ Stored produce increases in value as prices become higher and more volatile, resulting in households attempting longer storage periods to ensure either greater profit or reduced expenditure on food	**Food security** ❖ Reduced quality and quantity of food due to increased PH damage and loss [H, L, N] ❖ Increased dependency on non-self-produced food [H, L] and imported food [N] **Social** ❖ Sale of productive assets (erosion of coping strategies) [H] ❖ Erosion of traditional social safety nets, as demands on them increase [L] ❖ Decreased investment in human capital (education, health, and nutrition) [H, L, N, G] ❖ Reduced self-esteem, independence, and human dignity associated with receiving food aid when there is food shortage [H, L, N] **Financial and economic** ❖ Soaring costs of food relief and safety net programs [L, N, G] ❖ Resources withdrawn from long-term plans to meet short-term emergency needs, undermining economic growth and development ❖ [L, N, G] ❖ Rising food import bills [N] ❖ Re-orientation of public and private sector investments toward mitigating and adapting to climate change [N]

Impact on post-harvest activities	Impact on rural households' post-harvest assets	Impact on human well-being outcomes
moisture Increased risk of reduced seed viability especially for some legumes, such as groundnuts		
Key: PH=post-harvest, H=Household level; L=Local level; N=National level; G=Global level		

2.4 LIVESTOCK SUBSECTOR

Precipitation is critical for livestock survival, reproduction, and productivity. This is because water affects pasture germination, growth, and regeneration. In places where rainfall is adequate to support annual and perennial crops, pasture grasses and legumes can also grow well to nurture livestock. The main source of water for extensive animal production systems is rainfall. It is therefore paramount to understand and monitor the amount, frequency, variability, minimum, maximum, onset, and delays of rainfall in any livestock farming area.

Temperature also affects all classes of livestock. Average, minimum, and maximum and seasonal variations are crucial for livestock growth, regeneration, and survival. Very high temperatures, beyond 30°C, affect pasture quality, optimal animal physiology and regulate climate-related parasites and diseases like East Cost Fever and Rift Valley Fever.

The negative effects of increased temperature on feed intake, reproduction, and performance on various livestock species is reasonably well understood. For example, cattle, sheep, goats, pigs, and chickens, perform best at temperatures between 10°C and 30°C. But for each 1°C increase above that, all species reduce their feed intake by 3–5 percent (Rojas-Downing et al. 2015) This will have far-reaching effects on the quality and quantity of livestock species (Thornton et al. 2009). Increase in temperatures will also have widespread negative impacts on forage quality and thereby affect livestock productivity (McMichael et al. 2007). Simulations of the impacts of climate change on Africa's rangelands clearly indicate that very substantial changes in livestock feed resources that will occur. These changes will be detrimental to livestock production. Many regions in East Africa observe decreases in the quantity and quality of crop residues, further adding pressure on farmers and livestock feeding resources.

Fisheries and aquaculture are also highly vulnerable to changes in weather pattern, which can result in negative or positive impacts (Center 2007). Elevated water temperatures affect fish physiological processes, thereby affecting spawning, survival of juveniles, recruitment into the exploitable phase of population, as well as fish size, production, and yield. Increased flooding of freshwater bodies will have negative impacts due to watershed erosion, destruction of fish feeding and breeding habitats, decrease in primary productivity, and alteration of the normal resilience of the aquatic systems. Impacts can also be positive due to expansion of aquatic habitats for primary and fish production, especially during the dry season (FAO 2008). Drought exacerbates drawdown of lakes and reservoirs and reduces flow in river basins for spawning and primary production thereby affecting fish production (Halls 2009). Rise in the water levels of the lakes and seas leads to inundation of low-lying coastal areas and the intrusion of salty water, affecting the physical and **chemical properties** of the waters and the distribution of freshwater and marine fishes. The impacts ultimately affect fish population, production, and supply, thereby affecting the livelihoods of over 26 million people engaged in the primary and secondary sectors of the fisheries industry, as well as food security of the region (Halls 2009).

Climate change will have far-reaching consequences for dairy and meat production arising from the impact on grassland and rangeland productivity. The East African region is prone to periodic extreme changes in the weather including occasional flooding and prolonged dry spells all of which can result in famine and other stresses (EAC 2006). Heat distress suffered by animals will reduce the rate of animal feed intake and result in poor growth performance (Rowlinson 2008). Extreme heat will lead to stress and death of animals (Plate 1). Water stress and increased frequency of drought will lead to loss of livestock and associated resources. This will result in food insecurity and conflicts (as has been the case of the Karamajong in Uganda and Turkana in Kenya due to impacts of current climate change variability). Approximately 20–30 percent of plant and animal species are expected to be at risk of extinction if increases in global average temperature exceed 1.5°C–2.5°C (FAO 2007).

Climate variability and change has facilitated the recent and rapid spread of the blue tongue virus, an important ruminant disease observed in Africa (Sellers 1984), into Europe (Guis et al. 2012). Ticks that carry zoonotic diseases (diseases that can be transmitted from animals to people) have also likely changed distribution as a consequence of past climate trends. Temperature is an important limiting factor for livestock. As productivity increases, be it increasing milk yield in dairy cattle or higher growth rates and leanness in pigs or poultry, so metabolic heat production increases and the capacity to tolerate elevated temperatures decreases (Zumbach et al. 2008, Dikmen and Hansen 2009). In the long term, single-trait selection for productivity will tend to result in animals with lower heat tolerance (Hoffmann 2010), which reduces resilience.

Heat stress in dairy cows can be responsible for increases in mortality and economic losses (Vitali et al. 2009). It affects a wide range of parameters in poultry (Feng et al. 2008a). It impairs embryonic development and reproductive efficiency in pigs (Barati et al. 2008); and it affects ovarian follicle development and ovulation in horses (Mortensen et al. 2009). An increase in temperature tends to reduce animal feeding and growth rates (André et al. 2011, Renaudeau et al. 2011). Wall et al. (2010), showed that, in some regions, milk yields will be reduced by higher temperatures.

Climate change will affect the water resources available for livestock via impacts on runoff and groundwater. However, CO_2 concentration, temperature, and precipitation increment will favor certain pastures and disfavor others. In water-limited rangelands, the dominant means by which CO_2 will affect plant growth will be through changing patterns of plant water use. This may compromise pasture diversity and quality of feed. Water availability plays a major role in the response of pasturelands to climate change although there are differences in species response. Climate change will affect the proportion of browse species. The mix between legumes and grasses will be altered (IFAD 2008).

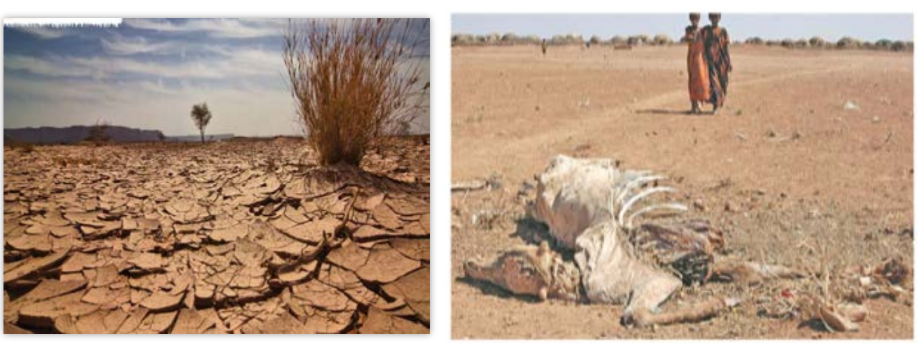


Plate 1: Current impacts of drought on pastures and livestock

Rising temperatures increase lignification of plant tissues, which reduce the digestibility and rate of degradation of plant species. This compromises efficient utilization of feeds and hence lowers productivity. Some of the indirect effects of climate change include reduced carrying capacity of rangelands, reduced buffering abilities of ecosystems, intensified desertification, increased scarcity of water resources, and decreased grain production leading to increased competition for feed resources between animals and livestock leading to upward pressure on prices (IFAD 2009).

Climate variability and change has severe impacts on animal health: there are climate-sensitive livestock diseases. Vector-borne diseases have been studied. These are Rift Valley Fever, tick-borne diseases, tsetse flies, and helminthoses. Mechanisms of spread and transmission are affected by duration of rainfall, extreme precipitation, and temperature. Some of the direct long-term effects result from (i) distribution and development rate of vectors, (ii) infection probability and development rates of pathogens in vectors, (iii) feeding frequency of the vector, (iv) heat stress and host resistance. Among the indirect impacts are (i) decline in biodiversity—monocultures of highly productive breeds of animals and (ii) land use changes for irrigation and deforestation. Rift Valley Fever (RVF) has been shown to be highly correlated with rainfall. Climate change will have important direct and indirect effects on RVF transmission. A rise in temperature increases the rate of transmission by increasing vectors' feeding interval, development rate, and reduces the virus's intrinsic incubation period. These effects only operate until a limit is attained where a further increase in temperature limits vectorial capacity (such as through increase in mortality rate).

Rainfall distribution is important in determining the breeding sites for the vectors. Excessive rainfall decreases vector population densities through flushing of the breeding sites. The indirect effects of climate—which include changes in host distribution and ecology—are thought to have more impacts on disease transmission than the direct effects mentioned earlier. The University of Liverpool has developed a model for predicting climate change effects on RVF distribution in East Africa (http://zgis186.geo.sbg.ac.at/hf_atlas/).

Models using ticks by Olwoch et al. (2007) show that the most important tick species are likely to expand in geographical range. These changes are unlikely to be affected by reduction in host diversity since ticks are generalists. Further, tsetse flies are likely to see shifts in distribution though the coverage is expected to shrink due to increase in human population. As for the effects of temperature on helminthiases, it is less discernible but improved population dynamics of vectors such as snails are likely to increase rates of transmission. The projected range shifts are shown in Figures 12–14.

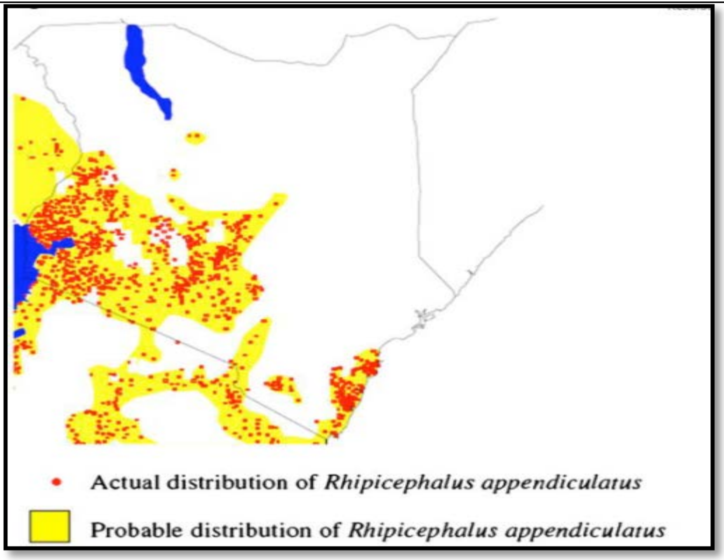


Figure 12: Actual and projected distribution of ticks under climate change models (Homewood et al. 2006)

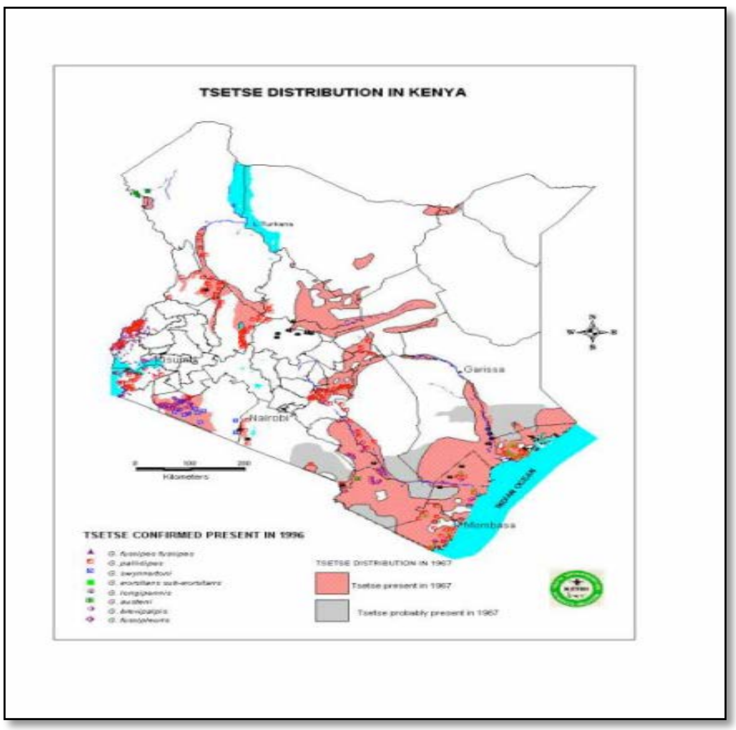


Figure 13: Projected tsetse fly (*Rhipicephalus appendiculatus*) distribution map for Kenya (Gachohi et al. 2012)

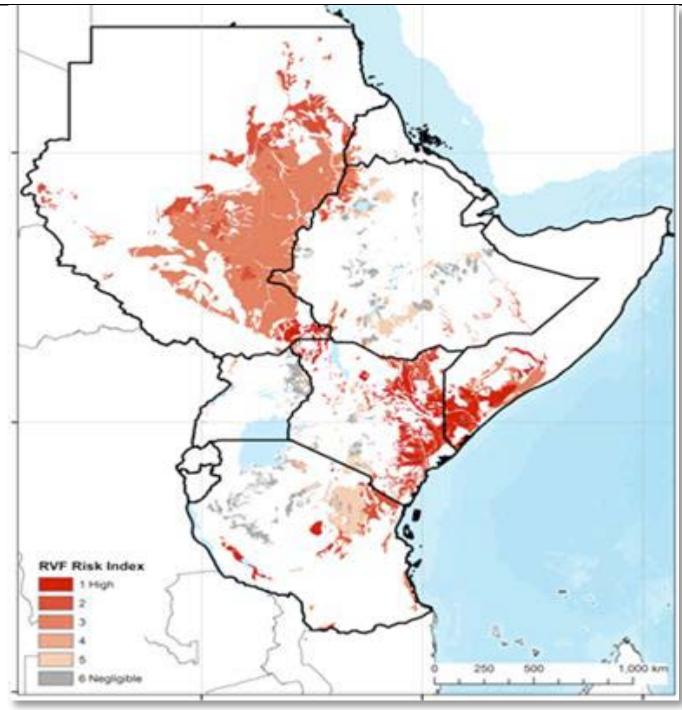


Figure 14: RVF risk map in East Africa (ILRI)

Figure 2.12–2.14: Current and future ranges for selected tick species

Thresholds for livestock vulnerability to climate change could be exceeded in the future. In the tropics and subtropics temperatures frequently rise above the "comfort zone" of 10°C–20°C (FAO 2009), and therefore, livestock are adapted to these higher temperatures. Heat stress can occur when temperatures are above 25°C for dairy cattle, when combined with high humidity, low air-flow, and direct sun light (Barman et al. 1985, Hahn 1999) (Table 5). In beef cattle the threshold temperature above which dry matter intake is adversely affected is 30°C with a relative humidity of below 80 percent, and if the relative humidity is above 80 percent the threshold temperature drops to 27°C (Hahn 1999).

Table 5: Comfort zone temperature range for different livestock classes

Temperature (° C)		
Class	Minimum	Maximum
Dairy cattle	10	25
Beef cattle	10	30
Pigs	10	37
Poultry	10	38

Source: FAO 2009, Jouda et al. 2004.

Thornton and Gerber (2010) summarizes the possible impacts of climate on livestock production (Table 6). Heat stress on animals will reduce the rate of animal feed intake and cause poor performance growth (Rowlinson 2008). Lack of water and increased frequency of drought in certain countries will cause a loss of resources. This will exacerbate existing food insecurity and conflict over scarce resources. The following sections provide an overview of the effects of climate change both on livestock and fisheries.

Table 6: Possible impacts of climate change in livestock production systems

Grazing systems	Non-grazing systems
Direct impact	Direct impact
❖ Extreme weather events ❖ Drought and floods ❖ Productivity losses (physiological stress) owing to temperature increase ❖ Water availability	❖ Water availability ❖ Extreme weather events
Indirect impacts	Indirect impacts
❖ Fodder quantity and quality ❖ Disease epidemics ❖ Host-pathogen interactions	❖ Increased resource price, e.g., feed and energy ❖ Disease epidemics ❖ Increased cost of animal housing, e.g., cooling systems

Source: Thornton and Gerber (2010).

2.5 FISHERIES SUBSECTOR

For fisheries and aquaculture, climate change has been reported to be already affecting the seasonality of some biological processes, altering marine and freshwater food webs, with unpredictable consequences for fish production, such as increased risks of species invasions and spreading of vector-borne diseases. Analysis of the vulnerability in the fisheries and aquaculture sector is based on cause-effect relationships and its impact on people, economic sectors, and socio-ecological systems. Within the LVB, climate change has now been recognized as a major concern that is likely to exacerbate existing poverty levels given its implications with respect to agriculture and food security, water resources, and natural resources including ecosystem goods and services, as well as its direct and indirect adverse effects on human heath (Mogaka et al. 2006, Mugisha et al. 2007).

Climate change will affect fisheries in diverse ways. Climate variables influence fisheries through a range of direct and indirect pathways. The key variables or drivers of interest to this sector include changes in water temperature, precipitation, salinity, river flow, nutrient levels, lake levels, storm frequency and intensity, and flooding (Lehodey et al. 2006, Brander 2007). Increase in the frequency and severity of extreme events, such as floods and storms, will affect fishing operations and infrastructure (Adger et al. 2005); changes in water quantity and quality will affect productivity, as well as the distribution and abundance of aquatic competitors and predators (Edwards and Richardson 2004, Hall-Spencer et al. 2008). In areas that experience water stress and competition for water resources, aquaculture operations and inland fisheries production will be at risk (Peters et al. 2014).

Increased precipitation will result in high levels of eutrophication, resulting in an increase in primary production, including algal production, which compete for oxygen with fish and are a major cause of spontaneous fish kills and stunted growth (Ficke 2007). Further, increased nutrients will lead to changes in the abundance and distribution of exploited species and assemblages (Lehodey et al. 2006, Dulvy et al. 2008), and may affect the capture of fish juveniles and fry from the wild for aquaculture use.

Climate change will lead to an increase in pests and diseases in fisheries due to increased temperature and reduced water quality (Marcogliese 2008). Increased precipitation may lead to pollution of fish farming facilities by heavy metals. These pollutants may accumulate in the body of the fish, exposing consumers to heavy metal poisoning. The consequences will be an increase in health problems associated with specific pollutants (Ficke et al. 2007). Toxicity of common pollutants like organophosphates and heavy metals to fish has been reported to increase at higher temperatures. Elevated toxicant concentrations in fish tissues can have sub-lethal effects that may include reduction of reproductive output. Increased uptake of exogenous toxicants and the synergy existing between high temperatures, poor environmental conditions, and the presence of ammonia suggests that an increase in global temperatures has the potential to lower productivity in wild fish populations and in intensive aquaculture systems (Ficke et al. 2007).

Increases in temperature may have negative physiological effect on fish. Freshwater fishes are exotherms, and cannot regulate their body temperature through physiological means. Therefore, their body temperatures are virtually identical to their environmental temperatures. This implies that increase in global temperatures will affect fishes by altering their physiological conditions, such as thermal tolerance, growth, metabolism, food consumption, reproductive success, and the ability to maintain internal homeostasis in the face of a variable external environment. As a result, fishes faced with changes in thermal regimes may increase or decrease in abundance, experience range expansion or contraction, or face extinction (Ficke et al. 2007). Increase in abundance will have positive effects on fish production and therefore on food security.

Solubility of oxygen in water has an inverse relationship with water temperatures. For instance, at 0°C, water holds about 14.6 milligrams of oxygen per liter, while at 25°C it holds about 8.3 milligrams per liter. This implies that fishes exposed to elevated temperatures can face "oxygen squeeze" where the decreased supply of oxygen cannot meet the increased demand. Given the probability of higher temperatures and increased biological oxygen demand, it is possible that levels of dissolved oxygen will decrease, leading to negative impacts to aquaculture and food security within the basin (Kalff 2000, Ficke et al. 2007). Warm temperatures may also lead to faster depletion of the limited oxygen supply in fish ponds. This may lead to increased stress in fish, or in some cases fish deaths leading to unemployment and food security (Ficke et al. 2007).

Increased rainfall may increase water availability, and hence increase aquaculture potential; however, it will also will carry many pollutants into water bodies and increase sedimentation due to soil erosion (IPCC 2007). More than 60 percent of the population in the LVB depends on rain-fed agriculture for a livelihood. Therefore, the observed dramatic decline of rainfall in the region will have a significant effect on aquaculture, and therefore on food security (WWF 2006). In addition, major water sources have experienced significant reduction of both water quality and quantity in the past 10 years. Pollution in main rivers has increased due to floods that wash agricultural pesticides and fertilizers into them (EAC 2011). The effects on the aquaculture subsector are evident and negative. For instance, deposition of soil may interfere with reproduction of tilapia by covering their nests and eggs (Mathews 1998). This will contribute to low fish production leading to food insecurity within the LVB. However, flooding in lowland areas of the LVB will prevent farmers from accessing their fish ponds, interfering with feeding and harvesting of fish. This may lead to unemployment and financial loses (when fishes are swept away) (IPCC 2007, Ficke et al. 2007). Abnormally high rainfall during El Niño events may destroy infrastructure such as roads and homes, as observed in Nyando. This interferes with both harvesting of the cultured fish and transportation to the markets (Ficke et al. 2007).

Increased drought associated with a decrease in precipitation and increased evapotranspiration will lead to decreased water in aquaculture facilities (IPCC 2007). Within the LVB, there is general agreement from local communities and meteorological and water agencies that available water is in decline. This is evidenced by receding shore lines and water levels in Lake Victoria. Similar recession has also been reported in the Mara River system, which has significantly reduced in the past ten years. Some local streams have completely dried up and some have reduced water levels and have become more seasonal. This decrease has negative impacts on aquaculture, leading to food insecurity (EAC 2011). The reduction in rainfall may compel people to encroach further on riparian areas of rivers and lakes, water catchment areas, wetlands, and mountain ecosystems for cultivation and the grazing of livestock. This has already been observed in some parts of the region, such as in Tanzania where crop cultivators and livestock keepers encroached on the wetlands owing to the persistent drought in most parts of the country between 1999 and 2001 (EAC 2011) with impact on fisheries.

Aquaculture is highly sensitive to climate change variables because cultured fish are less able to adapt to changes by migrating or changing their ranges to occupy more favorable conditions. Their restriction to ponds does not allow much choice. In addition, since fish culture in most developing countries depends on wild sources for fry and juveniles, changes in the distribution of fish species affect the success of aquaculture. Increased settlement around water bodies has affected fish habitats and their breeding grounds in the wild through eutrophication. Additionally, water resources have become polluted by effluents from both industry and agriculture. Most local communities that are entirely dependent on aquaculture within the LVB are poor. As a result, climatic changes make these individuals more vulnerable as they have no means to engage in alternative economic activities (EAC 2011). Table 7 presents other examples of the vulnerability of fisheries to climate change.

Table 7: Fish value chain vulnerability to climate change in East Africa

Point on value chain	Impact	Potential outcome for fisheries
Inputs and services	❖ Increased exposure of inputs (gear, boats, labor) to extreme weather, winds, and storms	❖ Destruction of inputs and gear ❖ Increased danger to boat crews and fishers
Production	❖ Changes in stream and groundwater temperature ❖ Change in hydrology regimes, a function of land use, precipitation, soil moisture, and evapotranspiration ❖ Hydrologic variability ❖ Eutrophication ❖ Water temperature effects on limnology ❖ Increase in ultraviolet (B) rays ❖ Water loss from lentic systems; evaporation is expected to be greater than precipitation ❖ Higher growth rates ❖ Higher incidence of disease ❖ Changes in water quality	❖ Shifts in primary production ❖ Changes in food web structure ❖ Shifts in secondary production (volume and distribution) ❖ Disease and species invasion ❖ Decreased areas to breed in shallow waters ❖ Less predictable seasonality of lakes
Trade and transport	❖ Roads and trade routes become impassable	❖ Lack of access to markets ❖ Changes in migratory/market routes and transport times
Processing	❖ Processing areas hit by unpredictable rain patterns	❖ Post-harvest losses ❖ Changes in processing technologies and costs due to abundance of new species

Point on value chain	Impact	Potential outcome for fisheries
Marketing	❖ Supply scarcity	❖ Price increases for available supply of fish ❖ Increased number of fishers ❖ Decreased revenues from declines in catch and/or stock abundance

Adapted from Ficke et al. 2007, WorldFish Center 2007, Daw et al. 2010.

2.6 SUMMARY

In summary, climate change will impact agriculture and food security. The gains made in agriculture and food security may be compromised by impacts from climate variability and climate change as summarized in Table 8.

Table 8: Summary of sector impacts

Subsector	Impacts
Agriculture and food security	❖ Climate change is an emerging challenge to agriculture development in Africa and its impact on the sector will be more severe in Africa than elsewhere. ❖ Food security in East Africa will be threatened by climate change. ❖ Rainfall across the LVB is highly variable both within and between seasons and the variability increases disproportionately from sub-humid to semi-arid regions. ❖ Climate change will complicate the existing challenges of socioeconomic development faced by the region. Recent trends and the current performance of agriculture expose a region that is progressively less able to meet the needs of its burgeoning population. ❖ Climate change will have far-reaching consequences for the poor and marginalized groups, the majority of whom depend on agriculture for a livelihood.
Crops	❖ Climate change will be an important driver of genetic erosion in the future and smallholder and subsistence farmers and pastoralists will be the hardest hit by disruptions in these services. ❖ Climate change and variability is likely to adversely affect seasonality and hence cropping patterns, thereby particularly affecting smallholder farmers. ❖ As a driver of crop productivity, climate variability and change will have implications for crop production in different parts of the region. ❖ Climate variability and change limits land suitability for agriculture in East Africa. Because of the climatic averages as well as extremes, and relationship between climate and soil characteristics, specific crops are usually localized. ❖ Climate change will affect crop production value chains at various stages. Hence a value-chain approach needs to be considered for climate change adaptation planning. ❖ Climate change will lead to shifts of farming systems: Some specific studies and analysis on potential impacts of climate change on crops in East Africa are available. ❖ Climate change may lead to major impacts from biotic stressors. Weeds are affected by climate and various atmospheric factors. Resultant changes in the geographic distribution of these crop pests and their vigor in current ranges will likely affect crops.
Livestock	❖ Climate change will have far-reaching consequences for dairy and meat production arising from the impact on grassland and rangeland productivity.

Subsector	Impacts
	❖ Climate variability and change will facilitate more frequent outbreaks and spread of diseases and pests with major impacts on the livestock sector. ❖ Heat stress in dairy cows can be responsible for increased mortality and economic losses. ❖ Carbon dioxide concentration, temperature, and precipitation increment will favor certain pastures and disfavor others. ❖ Rising temperatures increase lignification of plant tissues, which reduces the digestibility and rate of degradation of plant species. This compromises efficient utilization of feeds and hence lowers productivity. ❖ Climate variability and change has severe impacts on animal health due to effects on climate-sensitive livestock diseases such as RVF, tick-borne diseases, tsetse flies, and helminthoses. Mechanisms of spread and transmissions are related to duration of rainfall, extreme precipitation, and temperature.
Fisheries	❖ Climate change will affect fisheries in diverse ways. Several climate variables influence fisheries through a range of direct and indirect pathways. The key variables or drivers of interest to this sector include: changes in water temperature, precipitation, salinity, river flow, nutrient levels, lake levels, storm frequency and intensity, and flooding. ❖ Increased precipitation will result to high level of eutrophication, resulting in an increase in primary production, including algal production, which compete for oxygen with fish and are a major cause of spontaneous fish kills and stunted growth. ❖ Climate change will lead to an increase in pests and diseases in fisheries due to increased temperature and reduced water quality. Increased precipitation may lead to pollution of fish farming facilities by heavy metals. These pollutants may accumulate in the body of the fish, exposing consumers to heavy metal poisoning. ❖ Increase on temperature may have negative physiological effect on fish. Freshwater fishes are exotherms and cannot regulate their body temperature through physiological means. ❖ Increased rainfall may increase water availability, and hence aquaculture potential; however, increased drought associated with decreased precipitation and increased evapotranspiration will lead to decreased water in aquaculture facilities. ❖ Aquaculture is highly sensitive to climate change variables because cultured fish are less able to adapt to changes by migrating or by changing their ranges to occupy more favorable conditions.

3.0 CLIMATE CHANGE AND FUTURE PROJECTIONS FOR THE SECTOR

3.1 PROJECTING THE EAST AFRICAN CLIMATE

3.1.1 Rainfall

Climate change analysis and projections were developed using the Coordinated Regional Climate Downscaling Experiment (CORDEX). CORDEX downscaling is performed using multiple regional climate models (RCMs) as well as statistical downscaling techniques. Three future climate scenarios were used to project rainfall and temperatures to 2100. The three Representative Concentration Pathways (RCPs) RCP2.6, RCP4.5, and RCP8.5 designate increasing levels of radiative forcings (global energy imbalances), measured in watts per square meter, by the year 2100.

The RCP2.6 emission pathway is representative of scenarios leading to lower greenhouse gas concentration levels (van Vuuren et al. 2007). RCP4.5 is a stabilization scenario where total radiative forcing is stabilized before 2040 by deployment of a range of technologies and strategies for reducing greenhouse gas emissions (Wise et al. 2009), and the RCP8.5 is characterized by increasing greenhouse gas emission over time representative for scenarios leading to high greenhouse gas concentration levels (Riahi et al. 2007; refer to chapter 1 for the details of the models). The projections for the annual rainfall component under each of the three scenarios and time windows show relatively little change compared to the projections for the seasonal rainfall components. The short rains (October–December, or OND period) are projected to increase over most of the region under all the three scenarios (10–25 percent by 2030, and 25–50 percent by 2050; Figures 15a and 15b). By contrast, the long rains (March–May, or MAM period) are projected to decease over the northern part of East Africa but increase over the south eastern part of the region. The dry season rainfall (June–September, or JJAS period) is projected to decease over most parts of the region. The projected annual rainfall shows a tendency to increase over the LVB.

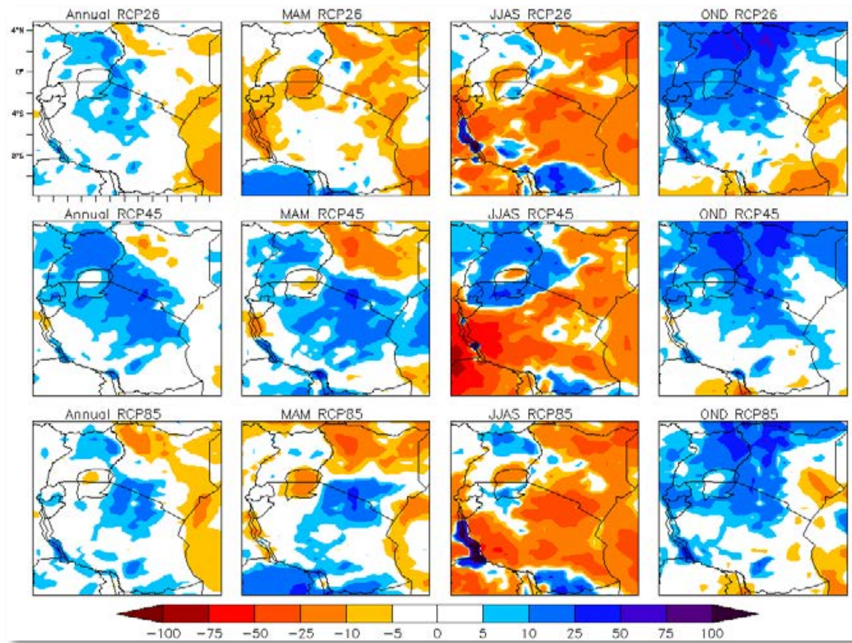


Figure 15a: Projected changes (relative to 1971–2000) over the EAC by 2030s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) rainfall components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

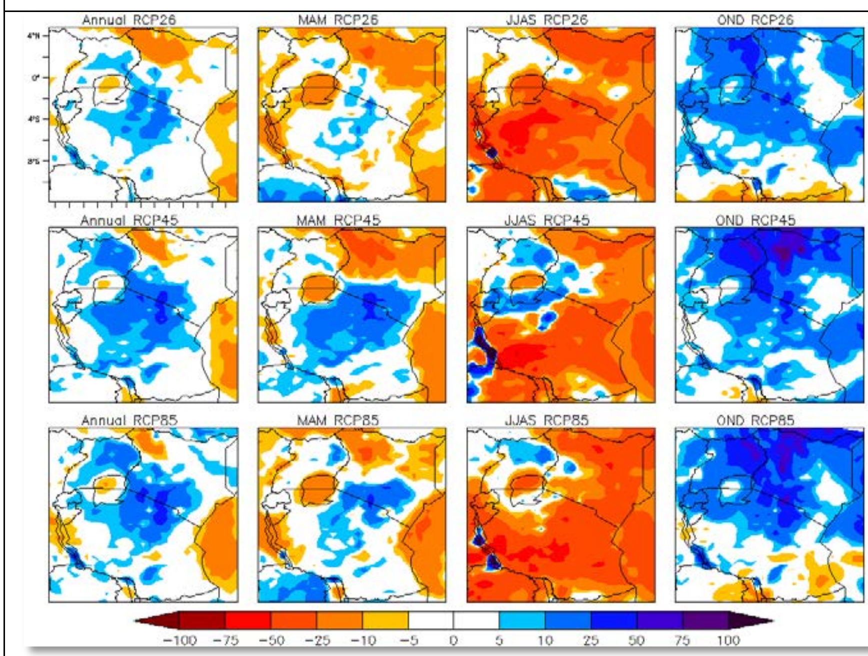


Figure 15b: Projected changes (relative to 1971–2000) over the EAC by 2050s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) rainfall components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

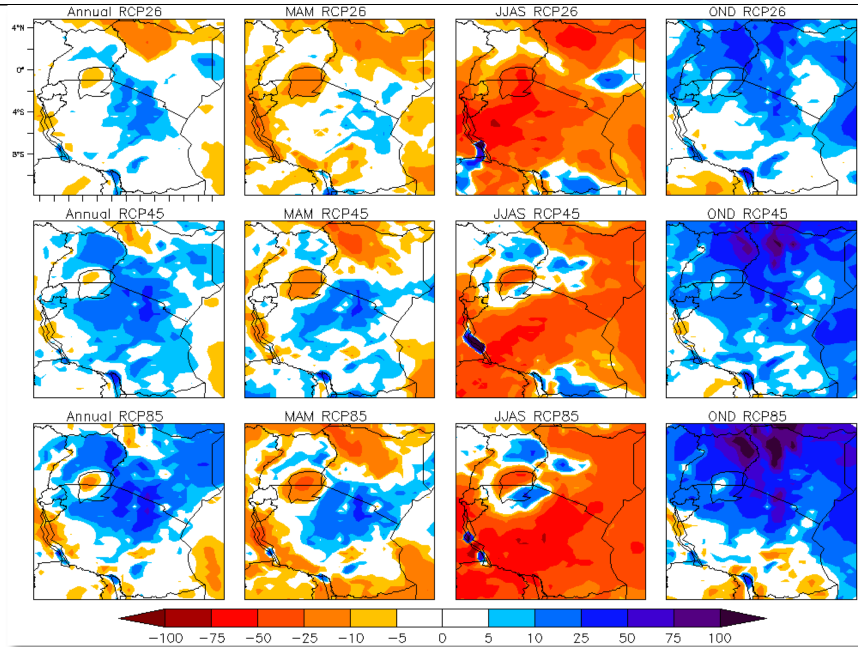


Figure 15c: Projected rainfall changes over the EAC by 2070s in annual (1st column), MAM (2nd column), JJAS (3rd column), OND (4th column). Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row) and RCP8.5 (3rd row).

Figure 15: Projected PPT changes (relative to 1971–2000) over the EAC (2030, 2050, 2070)

3.1.2 Maximum and Minimum Temperature

The projected changes in the maximum temperature component for the three scenarios (RCP2.6, RCP4.5, and RCP8.5) in the 2030s and 2050s periods compared to the reference period (1971–2000) are shown in Figures 16a–c. By 2030, maximum temperatures during the long rains (MAM), the dry season (JJAS), and the annual component will likely increase by 1.0–2.0°C over most parts of the region. The expected warming extent is greatest during the long rains (MAM) and the dry season (JJAS) and least during the short rains (OND). By 2050, annual maximum temperatures are expected to be 1.0–2.0°C higher under the RCP2.6, 1.5–2.5°C higher under the RCP4.5, and 2.5–3.5°C higher under the RCP8.5 scenarios over most parts of East Africa, with slightly less warming expected in some coastal areas.

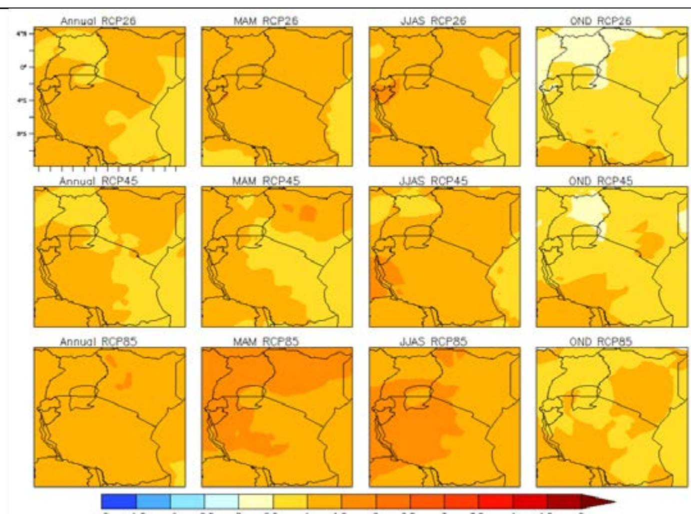


Figure 16a: Projected changes (relative to 1971–2000) over the EAC by 2030s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) maximum temperature components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

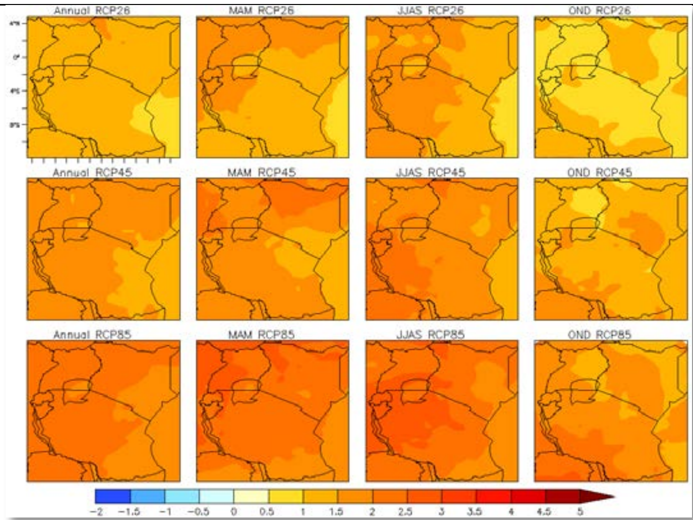


Figure 16b: Projected changes (relative to 1971–2000) over the EAC by 2050s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) maximum temperature components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

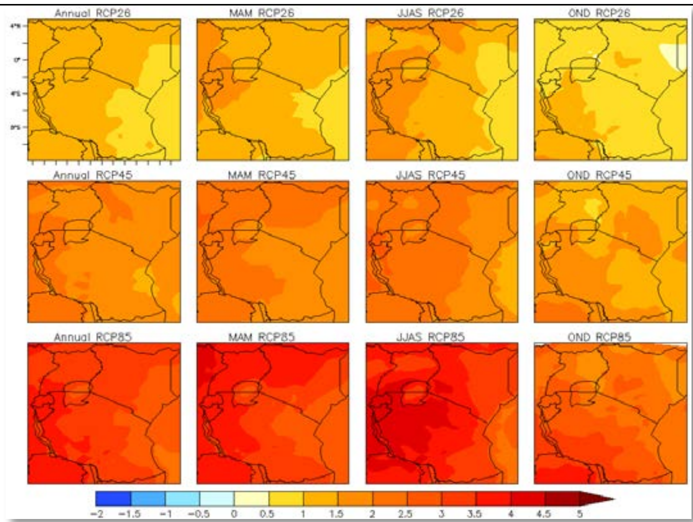


Figure 16c: Projected maximum temperature changes over the EAC by 2070s in annual (1st column), MAM (2nd column), JJAS (3rd column), OND (4th column). Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

Figure 16: Projected max temp changes (relative to 1971–2000) over the EAC by 2030, 2050, 2070

The projected changes in the minimum temperatures through time for the three scenarios are shown in Figure 17a–17c. The results suggest that there will likely be a greater increase in the minimum than the maximum temperatures in future. By 2030, almost all of the region will likely be 1.0–2.5°C warmer than the base period, with the greatest warming expected during the dry season months (JJAS) under the RCP8.5 scenario. By 2070, the projected increase in the annual minimum temperatures will likely be 4–5°C higher under the RCP8.5 scenario relative to the base period.

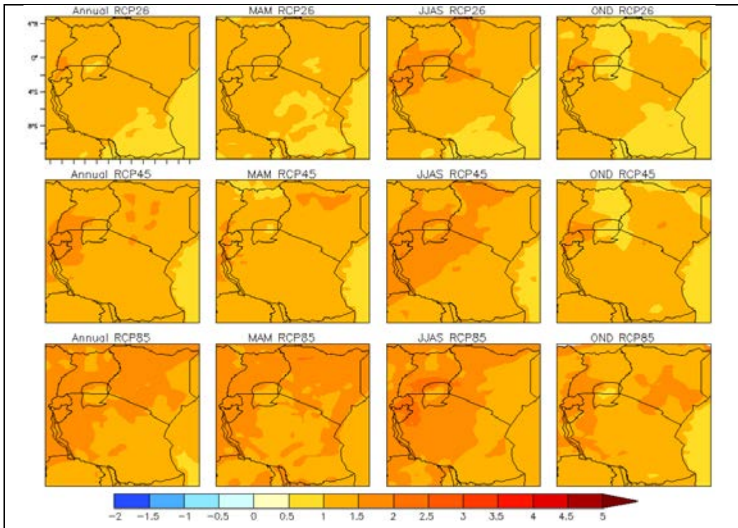


Figure 17a: Projected changes (relative to 1971–2000) over the EAC by 2030s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) minimum temperature components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

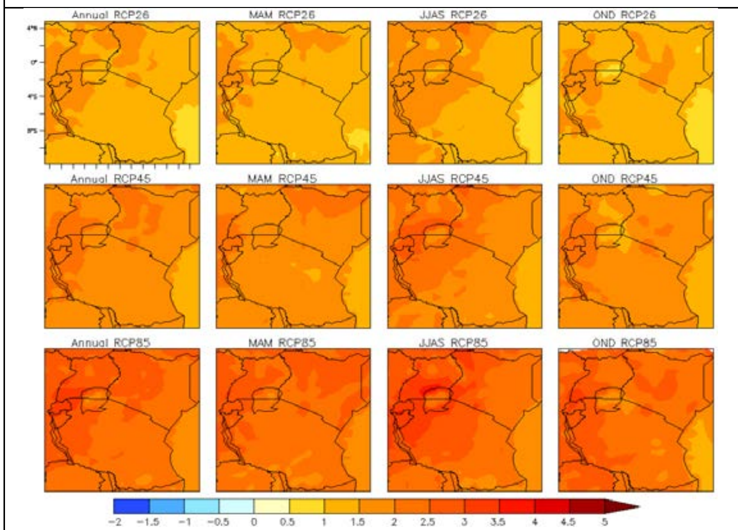


Figure 17b: Projected changes (relative to 1971–2000) over the EAC by 2050s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) minimum temperature components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

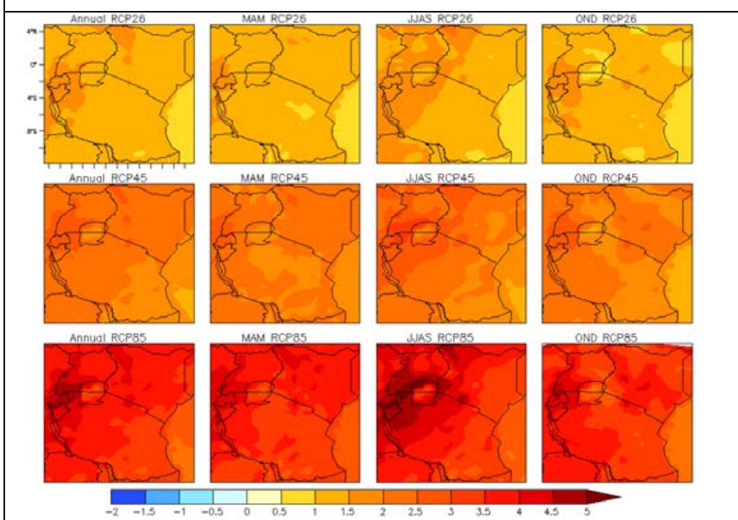


Figure 17c: Projected minimum temperature changes over the EAC by 2070s in annual (1st column), MAM (2nd column), JJAS (3rd column), OND (4th column). Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

Figure 17: Projected min temp changes (relative to 1971–2000) over the EAC by 2030, 2050, 2070

3.2 PROJECTING CLIMATE CHANGE FOR THE AGRICULTURE SECTOR IN THE LVB

Table 9 compares crops based on criteria of importance ranging from food security to vulnerability to disease and climate. Figure 18 summarizes of climate on the phenology of the crops from the least vulnerable crop, cassava, to the most vulnerable, coffee. This study focused on the impacts of climate on five crops: maize, rice, cassava, coffee, and tea.

Table 9: Comparison of commodity crops in the LVB based on their importance to local communities and vulnerability

	Maize	Coffee	Beans	Cassava	Banana	Sweet potato	Rice	Sorghum
Level of strategic priority (DSIP)	1	2	3	4	5	6	7	8
Importance for food security	Med	Low	High	High	High	High	Med	High
Importance for livelihoods	High	High	Low	Med	High	Low	High	Med
Level of integration and commercialization of value chain	High	High	Low	Med	High	Low	High	Med
Vulnerability to diseases	Low	High	Med	High	High	Med	Med	Low
Vulnerability to climate	Med	High arabica Med robusta	Med	Low	Med	Low	High	Med

Source: USAID 2013.

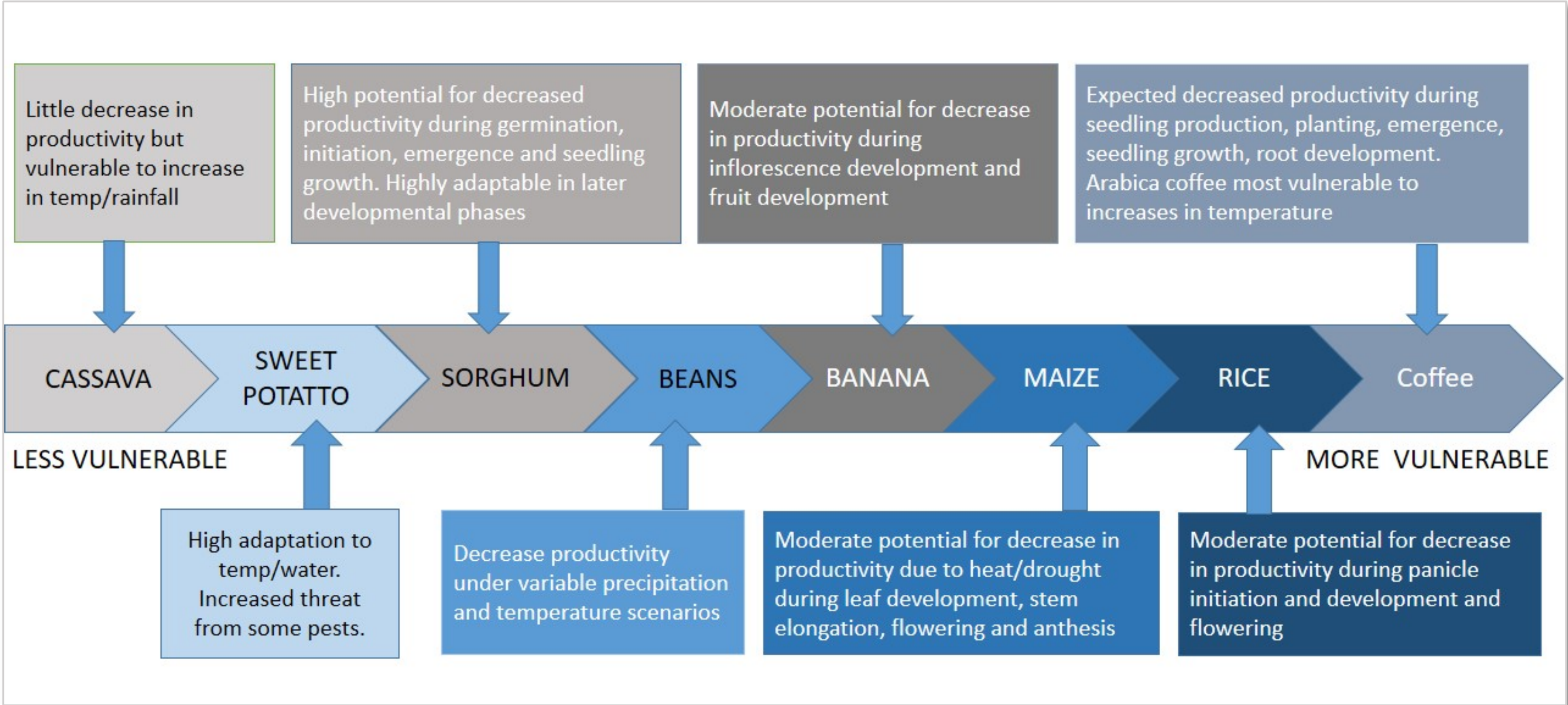


Figure 18: Phenological climate change vulnerability continuum of selected crops (source: USAID 2013)

3.2.1 Maize

The VIA team developed statistical tools for forecasting crop production in response to climate projections based on different RCPs. Nyanza and western Kenya were used as examples for this approach. Statistical methods for time series analysis and forecasting were used to analyze temporal variation in maize production in Kenya. The time series of historic observations of maize production were related to various time series of predictors (explanatory variables such as rainfall and temperature). The relationships established for the historic response series were used to forecast the likely future trajectories of the response series.

The VARMAX (Vector Autoregressive Moving Average Processes) statistical tool was used to model the dynamic relationships between the response and the predictor variables and to forecast most of the response variables. These extended models allowed modelling of several time series together; accounting for relationships among the individual component series with current and past values of the other series; feedback and cross-correlated explanatory series; co – integration of component series to achieve stationarity; seasonality; autoregressive errors; moving average errors; mixed auto – regressive and moving average errors; lagged values of the explanatory series; and unequal or heteroscedastic co – variances for the residuals.

The VARMAX model can be represented in various forms, including in state space and dynamic simultaneous equation or dynamic structural equations forms. The model allows representation of distributed lags in the explanatory variables. For example, maize production in year *t* can be related to maize production in year *t*-1, *t*-2 plus to annual rainfall in year *t*, *t*-1, *t*-2, minimum and maximum temperatures in years *t*, *t*-1, *t*-2, etc., simultaneously.

Univariate auto – regressive moving-average models with rainfall and minimum and maximum temperature were used as explanatory variables. Various lags in rainfall and minimum and maximum temperature were allowed and tested so that most of the models can be characterized as auto – regressive and moving-average multiple regression with distributed lags. The models also included and were tested for the significance of seasonal deterministic terms for monthly time series data. For some response variables dead-start models were used that do not allow for present (current) values of the explanatory variables. Heteroscedasticity in residuals was tested and, where appropriate, GARCH-type (generalized auto – regressive conditional heteroscedasticity) conditional heteroscedasticity of residuals was allowed. Several information-theoretic model selection criteria were used to automatically determine the AR (autoregressive) and MA (moving average) orders of the models. The specific criteria used were the Akaike information criterion (AIC), the corrected AIC, Hannan-Quinn criterion, Schwarz Bayesian criterion, also known as Bayesian information criterion, and the final prediction error. As additional AR order identification aids, partial cross-correlations were used for the response variable, Yule-Walker estimates, partial autoregressive coefficients, and partial canonical correlations. Parameters of the selected full models were estimated using the maximum likelihood (ML) method. Roots of the characteristic functions for both the AR and MA parts were evaluated for the proximity of the roots to the unit circle to infer evidence for stationarity of the response series.

The adequacy of the selected models was assessed using various diagnostic tools. The specific diagnostic tools used were as follows:

- Durbin-Watson test for first order autocorrelation in the residuals;
- Jarque-Bera normality test for determining whether the model residuals represent a white noise process by testing the null hypothesis that the residuals are normally distributed;

- F tests for autoregressive conditional heteroscedastic (ARCH) disturbances in the residuals. This F statistic tests the null hypothesis that the residuals have equal covariances;
- F tests for AR disturbance computed from the residuals of the univariate AR(1), AR(1,2), AR(1,2,3), and AR(1,2,3,4) models to test the null hypothesis that the residuals are uncorrelated; and
- Portmanteau test for cross-correlations of residuals at various lags.

Final forecasts and their 95 percent confidence intervals were then produced for the response series for lead times running up to 2100 for the three RCPS (Figure 19a and 19b).

Figure 19a shows the historic (1970–2014) and forecast (2015–2100) maize production series for three climate projection scenarios under changing climate in East Africa.

Figure 19: Projections of maize yield for East Africa

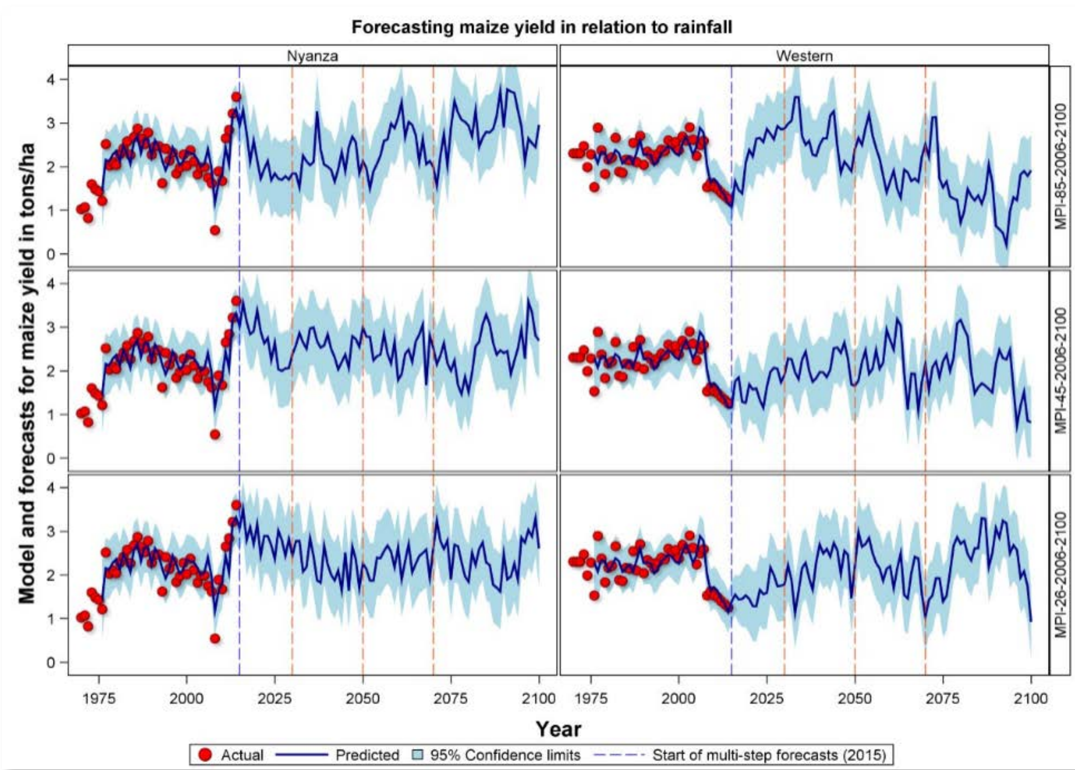


Figure 19a: Projections of maize yield for two regions of East Africa under RCP2.6, RCP4.5, and RCP8.5

There is marked inter-annual fluctuation in maize yield per hectare regardless of region or scenario. The fluctuations reveal cyclical patterns with widely time-varying trends, amplitudes, and phases for all regions and scenarios. As a follow-up, calculated averages of observed historic yields were developed for the periods 1970–1990 and 1991–2014. These were then compared to the averages of the forecast yields for the subsequent periods. Maize yield per hectare averaged 2.03 tons per hectare during 1970–1990 and 2.09 tons per hectare during 1991–2014 in the Nyanza region of Kenya. Corresponding averages for the western region of Kenya were 2.23 tons per hectare during 1970–1990 and 2.21 tons per hectare during 1991–2014. The predicted average maize yield per hectare was similar to the observed yield levels for both the 1970–1990 and the 1991–2014 periods for each of the two regions (Figure 19b and Table 25 in the appendix).

For each of the two regions there were discernible differences in the averages of the forecast maize yield across the three scenarios. For Nyanza the greatest increase in the average forecast yield relative to the observed average for 1991–2014 of 2.09 tons per hectare was 0.73 tons per hectare expected for 2015–2030 under the RCP2.6 scenario. Under the same scenario, the average forecast yields for 2031–2050, 2051–2070, and 2071–2100 were, respectively, 0.131, 0.235, and 0.321 tons per hectare greater than the average baseline value of 2.09 tons per hectare. Under the RCP4.5 scenario, the anticipated maize yield was 0.566, 0.496, 0.356, and 0.35284 tons per hectare greater than the baseline average of 2.09 tons per hectare during the 2015–2030, 2031–2050, 2051–2070, and 2071–2100 periods. This suggests a persistent decline in maize yield over time. Under the RCP8.5 scenario, in contrast, there was an evident and consistent increase in maize yield per hectare relative to the baseline average of 2.09 tons per hectare of 0.031, 0.060, 0.393, and 0.800 tons per hectare for the 2015–2030, 2031–2050, 2051–2070, and 2071–2100 periods (Figure 19b and Table 25).

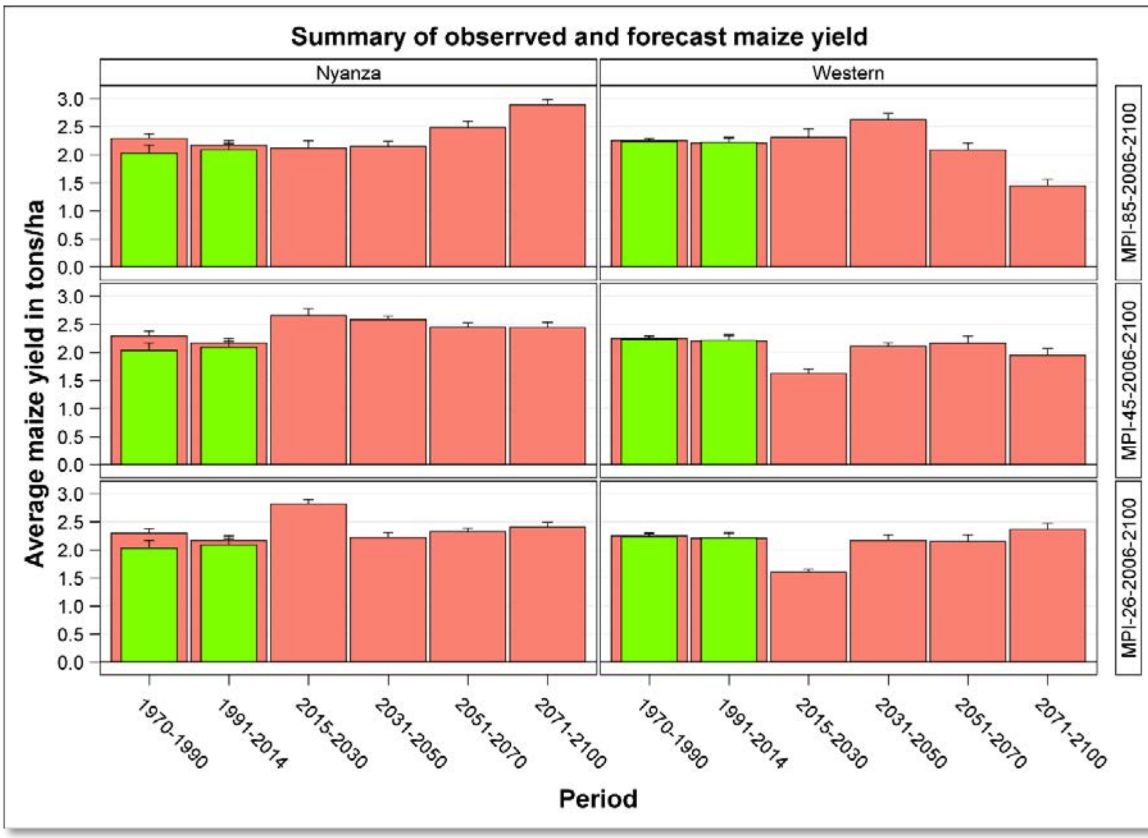


Figure 19b: Projections of maize yield for two regions of East Africa RCP2.6, RCP4.5, and RCP8.5 for 2015–2030, 2031–2050, 2051–2070, and 2071–2100.

For the western region, the patterns of projected maize yield suggest substantial drops in yield during the 2015–2030 period of -0.606 and -0.581 tons per hectare relative to the baseline average yield of 2.20 tons per hectare for the RCP2.6 and RCP4.5 scenarios. Average maize yields in the subsequent periods were also somewhat smaller than the baseline average for both the RCP2.6 (-0.054 to -0.039 tons per hectare) and RCP4.5 (-0.258 to -0.040 tons per hectare) scenarios except for the RCP2.6 scenario during 2071–2100 when the average yield was 0.156 tons per hectare greater than the baseline average. Maize yield under the RCP8.5 scenario showed a different temporal trajectory than under the other two scenarios. Maize yield first increased relative to the baseline average by 0.108 tons per hectare during 2015–2030 and 0.418 tons per hectare during 2031–2050. Maize yield then decreased strikingly by -0.122 tons per hectare during 2051–2070 and by -0.763 tons per hectare during 2071–2100 (Figure 19c and Table 25). A CIAT model of maize suitability found with much loss in LVB between 2020 and 2050 (Figure 19c).

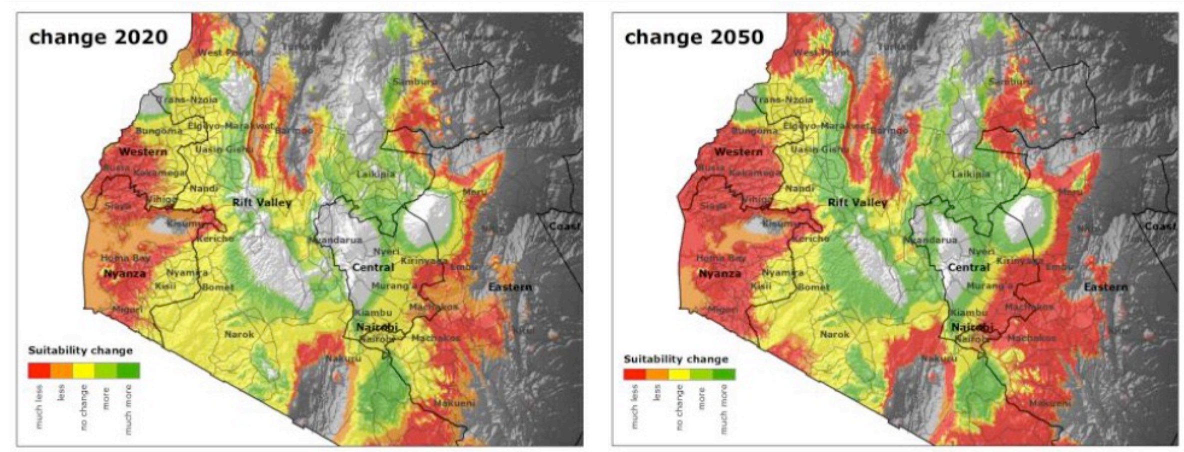


Figure 19c: Suitability change of maize (source: CIAT 2011)

Other Studies. Climate change impacts on maize have been widely studied. The results of the modelling work indicate an increase of maize yield with an increase in temperature up to 29°C, followed by a sharp decline in yield with further temperature increases (Schlenker and Lobell 2010). Others (Liu et al. 2008) have reported the optimum maize-growing temperature to be 25°C. Each degree day spent above 30°C has been found to reduce maize yield by 1 percent even under optimal rain-fed conditions (Lobell et al. 2011). Another report suggests that a 1°C increase above norm reduces maize yield by 10 percent (Lobell et al. 2011). Using worldwide temperature and yield trends, a decrease of 8.3 percent in maize yield per 1°C rise above normal has been established (Lobell and Field 2007). The findings suggest that at elevated temperatures, maize not only suffers from temperature stress but also becomes sensitive to moisture availability. Under rain-fed agriculture and potential variations in rainfall distribution under climate change, available soil moisture may not be able to meet increasing water demand.

Most of the currently cropped maize area in Africa is projected to experience negative impacts from climate change. Humid and West African countries (including those across the Sahel) are likely to be among the most negatively affected, with mean production losses between 20 and 40 percent by the 2050s [RCP8.5] equivalent to +2ºC above preindustrial temperatures (Figure 20). Crop yield losses in these areas will result from shortened cropping seasons and heat stress during the crop's reproductive period (Thornton et al. 2009). Significant positive or negative impacts from climate change on maize production may be unlikely to occur in some areas of eastern Africa, such as eastern Kenya where production may change much less, often within ±5 percent. As climate change intensifies, however, areas with production gains or stable production may tend to reduce their size and/or may disappear completely.

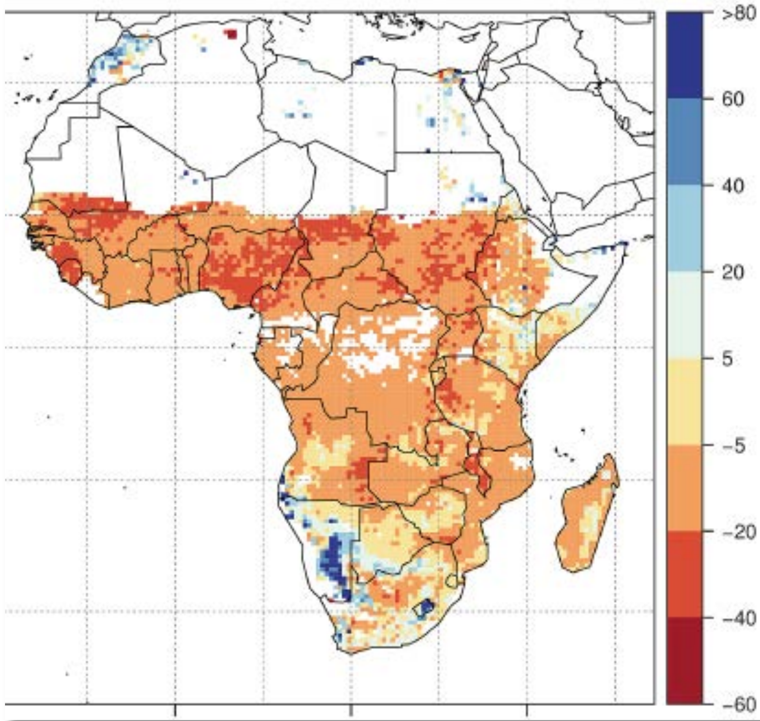


Figure 20a: Spatial distribution of percentage change in production by 2050s and RCP8.5 (high-end emissions) in relation to the mean production of 1971–2000. This figure was constructed using the outputs of the Agricultural Model Intercomparison and Improvement Project (Ramirez-Villegas 2015)

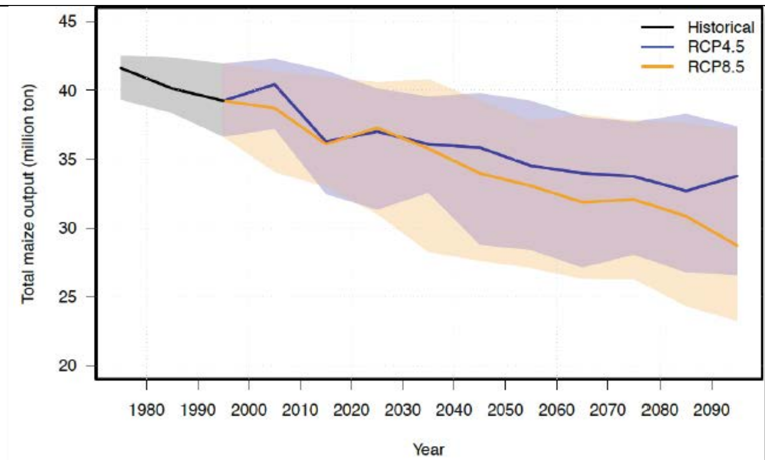


Figure 20b: Projected changes in maize production. Future projected African maize total production during the 21st century and two future emissions pathways: intermediate (RCP4.5) and high-end (RCP8.5) show large decline in production in Africa.

Figure 20: Changes in maize cropping under a changed climate

Table 10 shows averaged country yields of a scenario focused on East Africa as developed by FAO. The scenario is simulated production by 2055 compared with baseline of the year 2000. The table also shows the probabilities of maize yields less than 200 kilograms per hectare as an estimate of the probability of crop failure. In nearly three-quarters of the countries, yields decrease by 2055, as a result of temperature increases and rainfall differences. Maize is a C4 crop and is remarkably tolerant of high temperatures. It is unlikely that some other staple crops would be tolerant under climate change where even moderate scenarios (RCP2.6) envision a 1–2°C temperature increase. For example, beans (*Phaseolus vulgaris* L.) have a temperature optimum of around 21°C and large areas of Africa and Latin America reliant on this protein source may be badly affected by projected temperature increases.

Table 10: Calculated and simulated country yields and production differences to 2055 in smallholder rain-fed production systems in countries of East Africa (FAO 2001)

Country	FAO area, 2000 (ha)	FAO yield, 2000 (kg/ha)	Simulated yield (kg/ha), baseline	Simulated yield (kg/ha), 2055	Production change, baseline to 2055 (t)	Probability of yield <200 kg/ha, baseline	Probability of yield <200 kg/ha, 2055
Burundi	115,000	1082	2083	1761	-37,030	0.07	0.01
Kenya	1,500,000	1800	1154	1094	-90,000	0.21	0.18
Rwanda	75,000	840	2188	2039	11,175	0.22	0.10
Tanzania	3,010,591	847	1458	1246	638,245	0.06	0.04
Uganda	629,000	1742	1855	1592	165,427	0.04	0.04

As indicated in these models that use coarse continental-level data, it is important to compare regions using similar methodology. However, the impacts of climate variability and change on agricultural productivity at regional scales are complex, and may even be masked by aggregate and courser-level spatial analysis. This is especially true in East Africa due to the nature of spatial gradients, and temporally and spatially varying rainfall patterns. The CERES maize model embedded in DSSAT v4.5 was used to model local hybrid H614 under typical conditions. Climate variability and fertilizer effects were analyzed with point simulations using observed weather (1984–2011). Project climate change impacts were examined using high-resolution (6 kilometer) modelling and data sets—WorldClim for current climate and 4 global climate models (GCM) for projected climate. Only the HadCM3 results are illustrated.

Simulations using historical weather show yield variability from 45 percent in a dry site to 21 percent coefficient of variation in a wet site (Alagarswamy et al. 2015; Figure 21). Water deficit levels in much of Uganda and south-central Tanzania worsen as precipitation declines and temperatures increase. Deficit in northeast Kenya improves but is too dry to grow maize. In general, projected future warming led to a reduction in the length of growing season with decreases in maize yields in central Uganda, coastal Kenya, and eastern sections of Tanzania. In Rwanda and Burundi, the projections are mixed in some areas with potential increases in some and declines in others.

The Alagarswamy et al. study illustrates the benefits of high-resolution processed-based crop modelling to identify climate change impacts on crops, especially heterogeneous regions. The East Africa regional average change in maize yield is only -1 percent. This conceals the localized impacts from -3,000 to +3,000 kilograms per hectare (Alagarswamy et al. 2015). Unfortunately, the yield declines are in major producing zones of East Africa, raising serious questions about food security in the region. Future adaptation needs to account for high spatial variability and impacts of extreme hot temperatures.

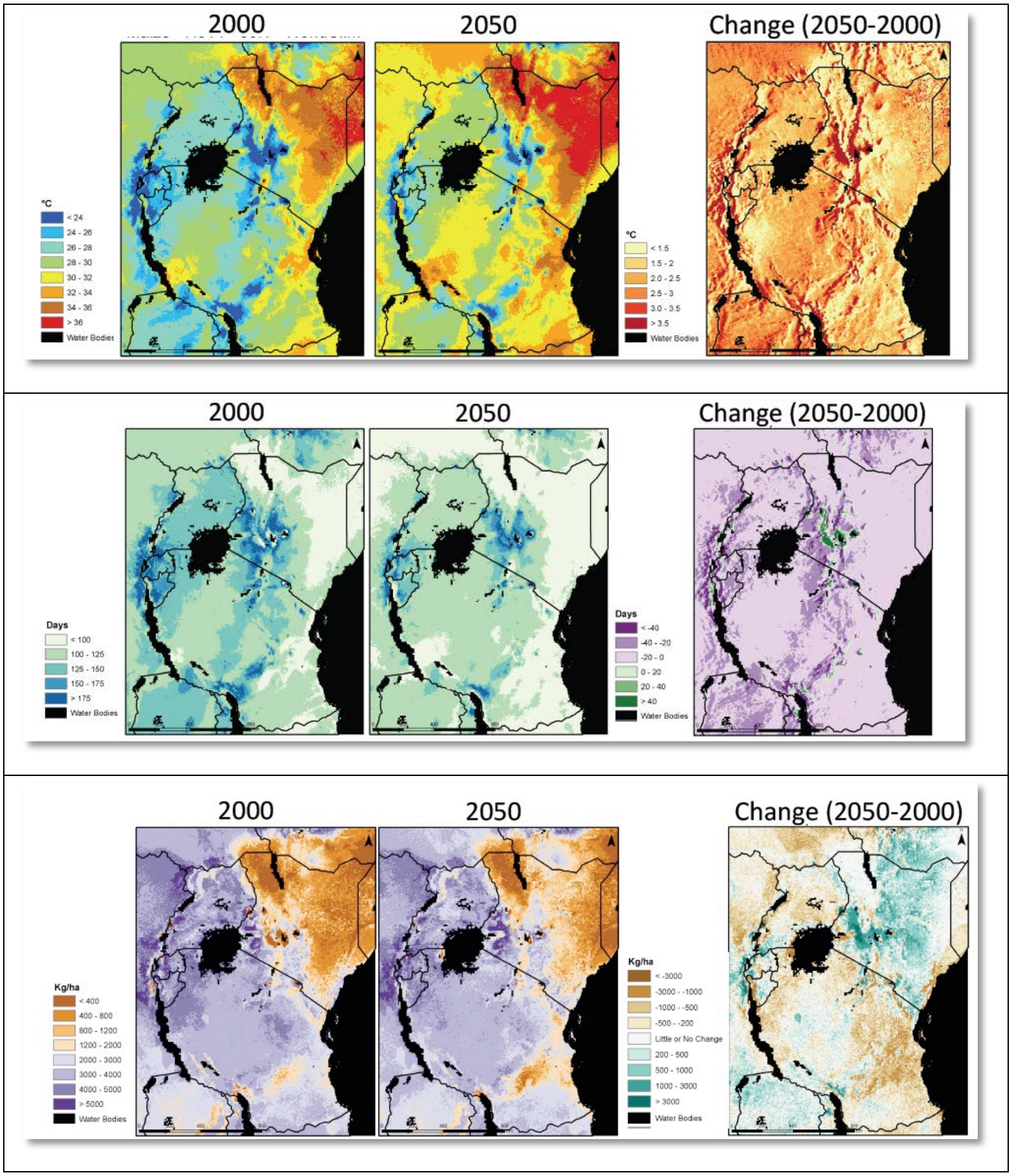


Figure 21: Impacts of climate change on maize production in East Africa. Top: changes in temperature between 2000 and 2050; middle: length of the growing season; bottom: maize production in 2000, 2050, and changes between 2000 and 2050 (source: Alagarswamy et al. 2015)

3.2.2 Rice

Rice is a vital crop in East Africa and is primarily grown by smallholder farmers as a rain-fed crop (excluding Kenya, where the majority of rice is irrigated). It is the second most important crop in Tanzania and the third most important in Kenya (Salami et al. 2010). It is grown as upland rice, lowland rain-fed rice, mangrove swamp rice, floating rice, or irrigated rice (Salami et al. 2010). As most of the rice in East Africa is not irrigated, climate change–induced rises in temperature and increased variability in rainfall may affect production. The extent of this impact will vary by production system. Upland and lowland rice, which constitute about 80 percent of rice production area in the region, are projected to be the most vulnerable (McCarthy et al. 2011). It is also reported that that climate change will affect rice production in East Africa by increasing heat stress, drought, flooding and submergence, and salt stress (Manneh et al. 2007). In rain-fed production systems, drought is the most important production limiting factor due to the crop's sensitivity to moisture stress: yield is significantly reduced even under a mild drought (Guan et al. 2010). Similarly, heat stress results in high spikelet sterility, low tillering, stunting, and accelerated development, which eventually leads to reduced yield.

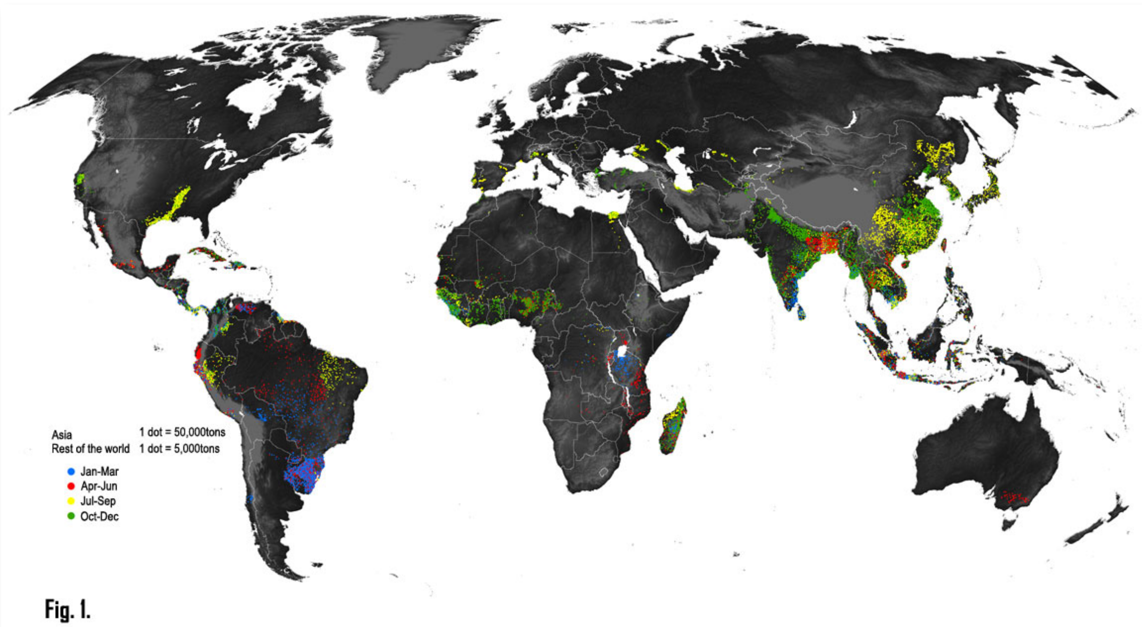


Figure 22: Map of world rice production indicating the LVB as an important rice area in East Africa and grown in January–March and April–June

Brown (2009) indicates 1°C increase in temperature above norm reduces rice yield by 10 percent. According to Liu et al. (2008) rice has an optimum growing temperature of 25°C, and temperature increases should result in higher rice yield in most rice-growing countries. Further work by Lobell and Field (2007) reported a 0.6 percent decrease in rice yield per 1°C increase in temperature. Simulation studies against temperature projected a 2.6 percent yield increase with 1°C temperature rise to about 16 percent yield reduction for a 4°C rise in temperature. A quadratic relationship between temperature and rice yield at 330 ppm of CO_2 ended up with zero yield at 37°C (Boote et al. 2005, Kim et al. 2003). As a C3 crop, rice is expected to benefit from increased atmospheric CO_2 concentrations. However, increases in temperature have the potential to negate any benefit of elevated CO_2 in rice yield (Ainsworth 2008). Projections of the impact of climate change on rice in the region vary among studies. Lobell et al. (2008) used 20 GCM models and projected a slight increase (<5 percent) in rice production in East Africa by 2030 compared to 1998–2002 (Lobell et al. 2008).

Using an impact model, projections found a 0.24 percent increase in rice yield in eastern Africa and a 2.32 percent reduction in southern Africa by 2050. Another study using the Improved Global Agro-Ecological Zones method under the A1B storyline also projected about 1 percent yield gain in rice in eastern Africa by the 2090s compared to 1990s (Tatsumi et al. 2011). When projection was done using the NCAR and CSIRO models, results showed that about a 15 percent reduction in yield under the A2 scenario by 2050 in Sub-Saharan Africa without considering carbon fertilization (Nelson et al. 2009). Variations in rice yield projections among different studies are likely due to the difference in scenarios and models used in the prediction. Based on the temperature projections, eastern Africa could lose 4–8 percent, 8–13 percent, and 8–16 percent of rice yield under B1.

3.2.3 Cassava

Cassava is known to be resilient to climate change due to its tolerance of high temperatures and intra-seasonal drought (Jarvis et al. 2012). However, if a prolonged drought period (>2 months) falls during the root thickening initiation state, a root yield reduction of up to 60 percent may occur (Jarvis et al. 2012). Cassava shows better yield gain than grain crops at higher CO_2 concentrations, can recover from very long drought periods, and exhibits increases in optimum growth temperature under elevated CO_2 levels (Rosenthal and Ort 2012). These qualities make cassava a suitable crop in a future that is projected to experience elevated CO_2, increased temperature, and variable rainfall patterns. The findings are supported by other researchers who projected minimum impact, if not positive, or at least better performance of cassava than other crops. Cassava is an imporatnt crop in the LVB as indicated in Figure 23.

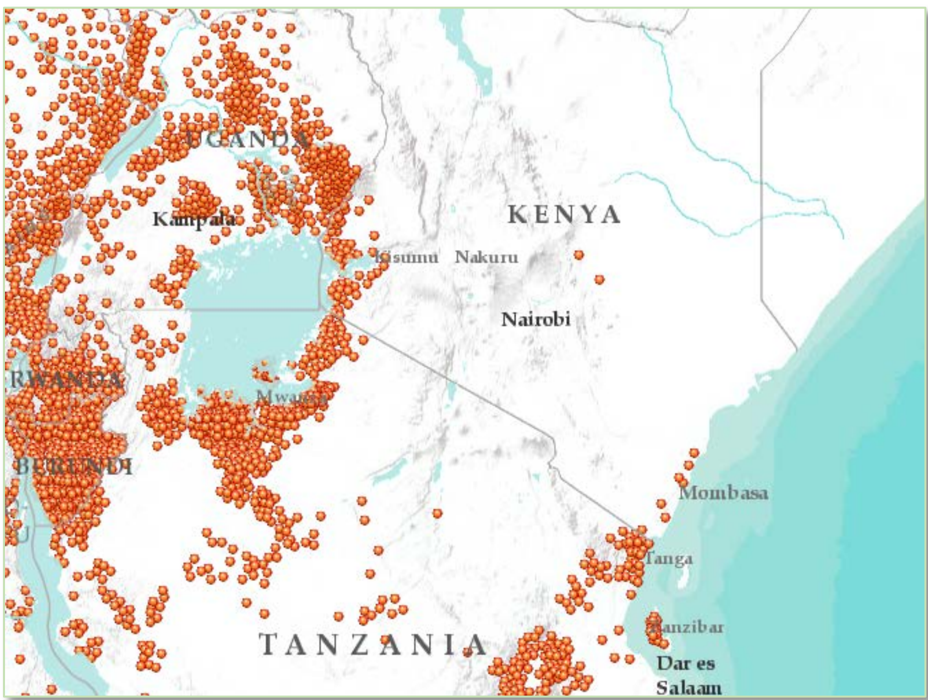
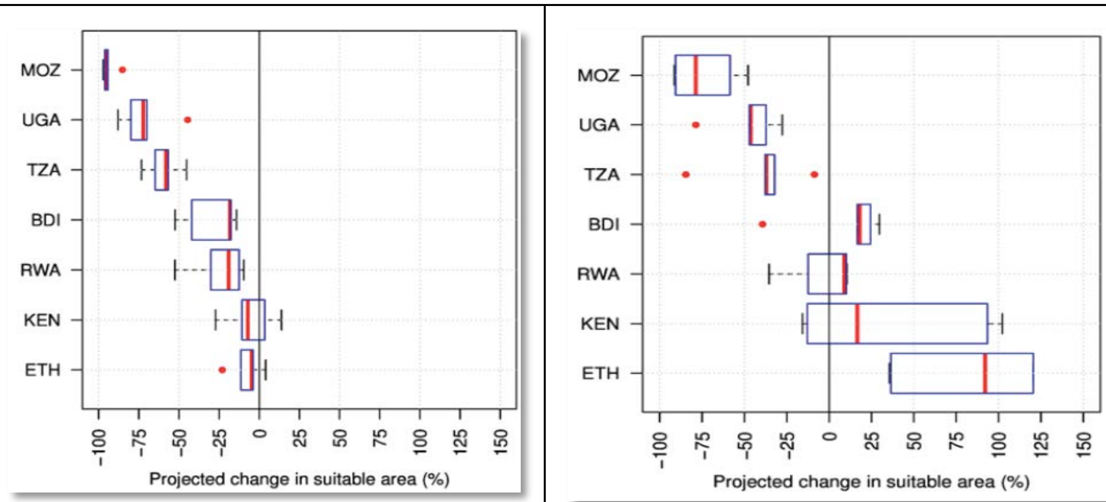


Figure 23: Cassava distribution in the LVB. Note: Each point on the map is equivalent to 500 hectares of land in cassava cultivation (source: Carter et al. 1992, CIAT 2002)

3.2.4 Coffee

Tea and coffee are grown throughout the five East African countries, mostly by smallholders as a cash crop. The production system employs millions of people in the region. While arabica and robusta are the dominant commercially produced coffee varieties grown around the world, arabica is dominant in East Africa. Kenya and Rwanda grow arabica. Uganda predominantly grows robusta, while Tanzania grows both types, but mostly arabica. Optimum growing temperature for arabica is 18–23°C while for robusta is 22–26°C (Jaramillo et al. 2011). Hence, arabica is cultivated in high altitudes, while robusta is cultivated in lowlands. Higher temperature hastens development and ripening of the cherry, impacting both productivity and quality of coffee.

Climate models indicate highly negative impacts of climate change on arabica coffee, with more than 50 percent of the coffee growing areas of Uganda and Tanzania disappearing, 20–50 percent of the areas in Burundi and Rwanda reducing significantly, and the least significant (but still noticeable) negative effects on Kenya (Figure 24). For robusta coffee, models indicate that two East African countries might experience substantially negative impacts: Uganda and Tanzania, whereas Burundi, Kenya, and Rwanda are more likely to experience gains in robusta-suitable areas (Figure 25). Based on these results, it is likely that two phenomena will be observed for coffee in East Africa: (1) an overall reduction in arabica growing areas accompanied by migration and hence concentration toward higher altitudes; and (2) a replacement of heat-stressed arabica areas (< 1,500 m.a.s.l.) by the more heat-tolerant robusta (Bunn et al. 2015).



Note: Changes in suitable area are calculated as the percentage of area suitable in the future relative to the area suitable in the historical period. Note that this scenario and period (2050s, RCP8.5) is roughly equivalent to a global mean temperature of about +2°C above preindustrial levels. (Ramirez-Villegas 2015)

Figure 24: Projected changes in percentage area suitable for arabica (left) and robusta (right) coffee for 2050s for RCP8.5 (high-end emissions).

(a) Changes in production—Coffee in Tanzania

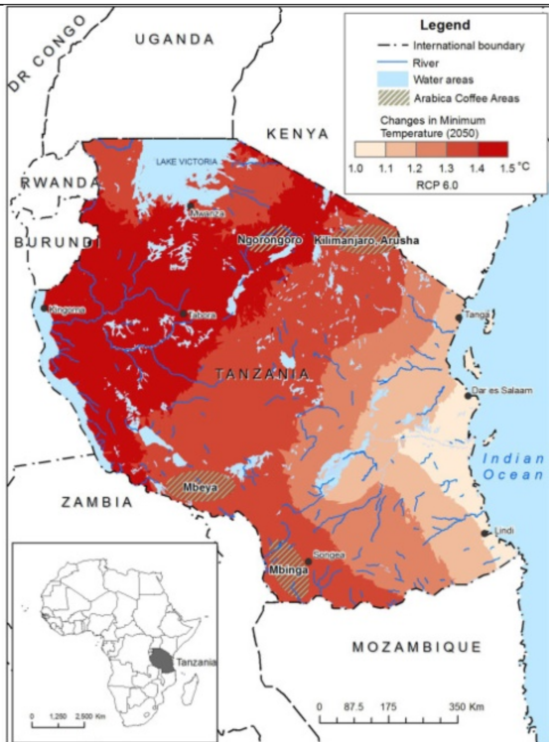
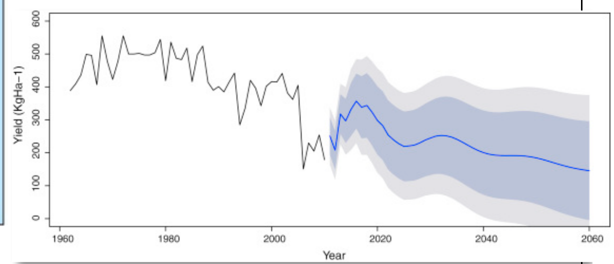


Figure 25: Recent studies predict severe climate change impacts on *Coffea arabica* (*C. arabica*) production. However, quantitative production figures are necessary to provide coffee stakeholders and policymakers with evidence to justify immediate action. Using data from the northern Tanzanian highlands, Craparo et al. (2015) demonstrate for the first time that increasing night time (Tmin) temperature is the most significant climatic variable responsible for diminishing *C. arabica* yields between 1961 and 2012. Projecting this forward, every 1°C rise in T_{min} will result in annual yield losses of 137±16.87 kgha^{-1} (P<0.0001). (source: Craparo et al. 2015)



According to the ARIMA model (autoregressive integrated moving average), average coffee production will drop to 145 ± 41kgha^{-1} (P<0.0001) by 2060 (Craparo et al. 2015). Consequently, without adequate adaptation strategies or substantial external inputs, coffee production will be severely reduced in the Tanzanian highlands in the near future. Attention should also be drawn to the arabica growing regions of Kenya, as substantiated time series evidence shows these areas share strikingly similar minimum temperature trends. This is the first study on coffee, globally, providing essential time series evidence that climate change has already had a negative impact on *C. arabica* yields.

(b) Suitability of arabica and robusta coffee in Uganda—coffee in Tanzania

In Uganda, arabica is grown in the highland areas on the slopes of Mount Elgon in the east and Mount Rwenzori and Mount Muhabura in the southwestern and north western regions. The current suitability of arabica coffee in Uganda, together with suitability changes in the future (2030 and 2050) (adapted from Läderach and van Asten 2012). The current climate was estimated using historical climate data from WorldClim, which includes 19 bioclimatic variables that are derived from monthly temperature and rainfall values to generate more biologically meaningful variables. The future climate was estimated using the results of 21 GCMs developed by the IPCC. The IPCC scenario SRESA2a (business as usual) was used. Future suitability predictions were then assessed through each of the GCM models via the software MAXENT (Maximum Entropy).

The results of the modelling indicate that if the same coffee production systems are kept with the same coffee varieties (this means that nothing changes and coffee production systems stay the way they are currently), then the areas suitable for arabica will drastically change and become less suitable. The green (more suitable) areas in the figure become smaller in 2030 and 2050 compared with the map showing current suitability. The yellow, orange, and red (less suitable) areas increase. Apart from climate change the smallholder coffee farmers in Uganda are vulnerable because of various constraints negatively affecting their livelihoods (i.e., increasing pests and disease pressure, decreasing soil fertility, poor agronomic practices, post-harvest challenges, poor market information and access, gender imbalances, poor extension services, and institutional challenges). There is increasing consensus that to be undertaken, and to be successful, adaptation strategies need to address those challenges (e.g., improving food security of producers in the short term).

In Uganda, the total area suitable for growing robusta coffee would be dramatically reduced with a temperature increase of 2°C (Smonett 1989). Only higher areas would remain, the rest would become too hot to grow coffee. The United Nations Environment Programme study shows the vulnerability of developing countries, whose economies often rely heavily on one or two agricultural products (Figure 26).

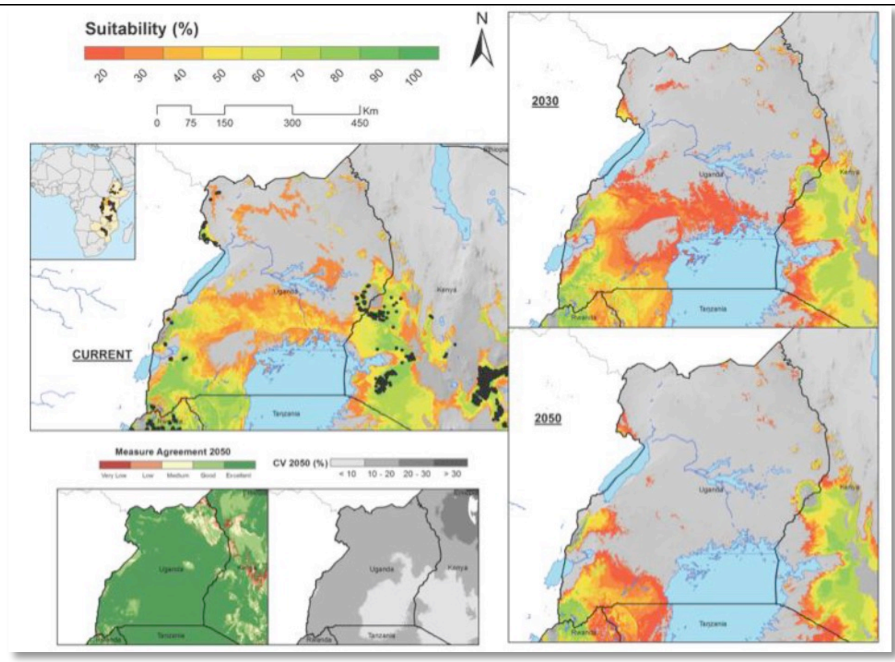


Figure 26: Predicted (according to MAXENT) suitability for coffee production in arabica coffee-producing area in Uganda today, in 2030, and in 2050

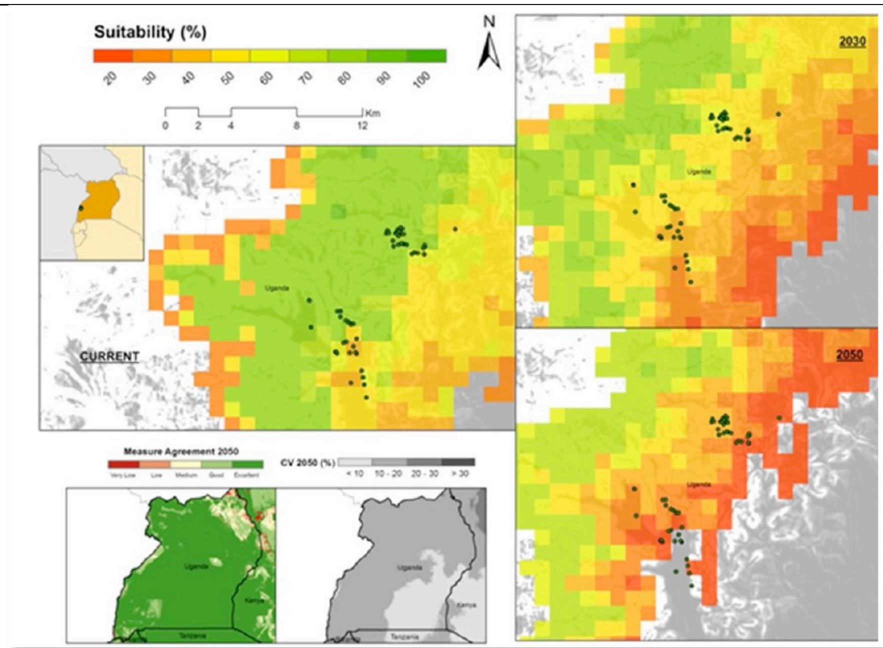


Figure 27: Predicted (according to MAXENT) suitability for coffee production in arabica coffee-producing area in the Rwenzori Mountains today, in 2030, and in 2050

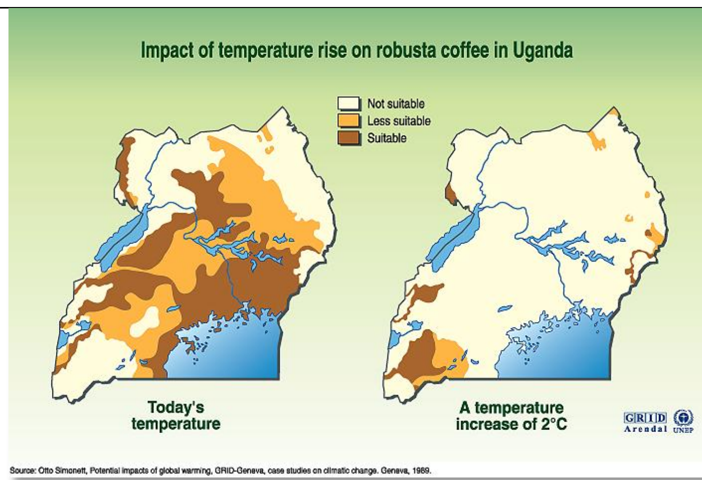


Figure 28: Potential impacts of climate change on coffee production in Uganda Source: Smonett 1989

3.2.5 Tea

East Africa is one of the world's major tea-producing areas (Figure 29). The region's tea sector will be significantly affected by climate change due to its dependence on stable temperatures and consistent rainfall patterns. Some of the specific impacts and challenges for the tea sector are described in Table 11.

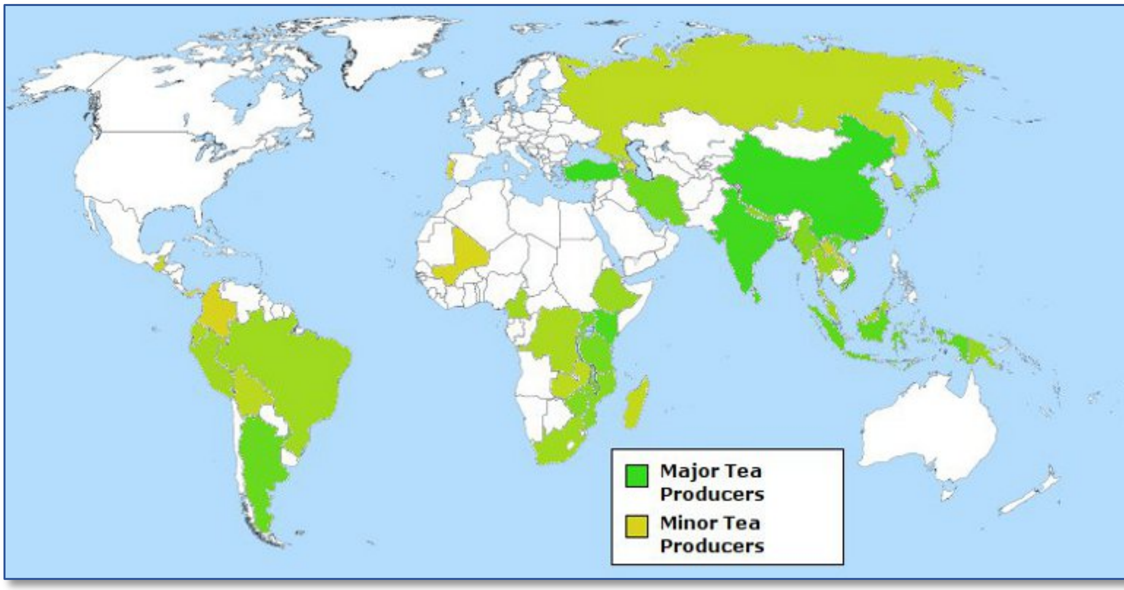


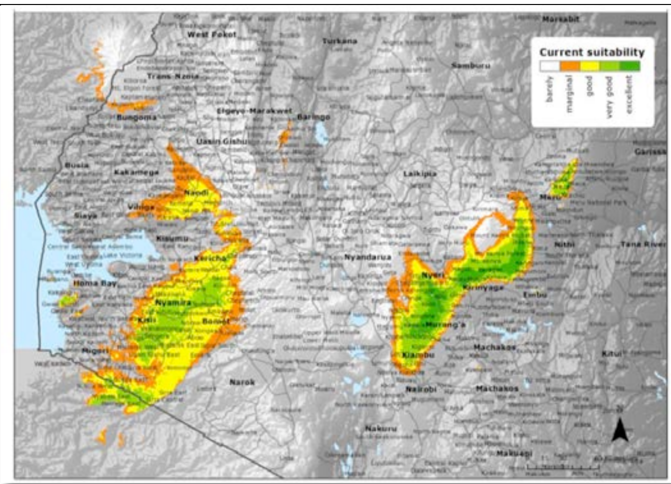
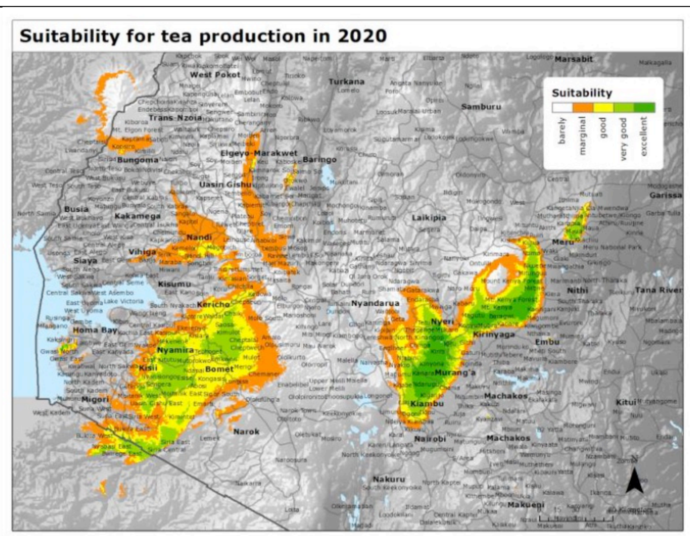
Figure 29: The main tea-producing countries in the world

Table 11: Potential climate change impacts for tea producers

Climate change problem	Impact
Increased temperatures	Drying of the soils causing reduced water content in the tea, decreasing yields and negative impacts on quality
	Drying of the soils causing increased soil erosion
	Arrival of pests and diseases not previously present
	Changes in the suitability of existing tea-growing areas
	Sun scorch damage decreasing yields and lowering tea quality
	Biodiversity loss (including tree loss)
Reduced water content of tea crop	Decrease in leaf quality
	Reduced resilience of tea crops
Changing rainfall patterns	Uncertainty in when to apply fertilizers
	Extreme rainfall events
	Water scarcity and drought
Increase in extreme weather events such as droughts, hail storms, floods, frosts, and landslides	Crop damage and failure
	Increased financial vulnerability of tea farmers
	Soil fertility loss through erosion
	Frost damage
Reduced productivity of subsistence crops for tea farmers	Increased vulnerability of tea farmers through food insecurity

Source: International Trade Centre 2014.

IPCC modelling predicts that average annual rainfall will increase by 4 percent. However, this will likely be counteracted by increased evapotranspiration resulting from more than 10 percent temperature increase averaging an additional 2.3°C by 2050. It is also predicted that the maximum yearly temperature will increase from 26.6°C to 29°C and the minimum temperature from 8.9°C to 11.1°C. With such changes, the altitude at which it is suitable to grow tea is likely to change. Optimal tea growth currently occurs at altitudes of between 1,500 and 2,100 meters above sea level (masl) (Figure 30a). By 2050, CIAT predicts that optimal tea growing will occur at altitudes of between 2,000 and 2,300 masl. These changes are not predicted to be equal across tea-growing regions, and while many regions are demonstrating a reduced suitability for tea growth, some are gaining suitability. The key results are as follows: The region around Nandi shows a slight decrease in suitability by 2020, but by 2050 significant loss in suitability is observed (Figures 30b and 30c). By 2050, tea-growing areas in the western districts seriously decrease in suitability. In general, areas of tea suitability shift to higher altitudes with some areas, especially in the central region and some parts of the Rift Valley gaining in suitability. Finally, the areas around Mount Kenya remain highly suitable in 2050 (Figure 30c).

	**Figure 30a:** Current suitability for tea production within tea-growing districts of Kenya (Source: CIAT 2011)
	**Figure 30b:** Projected suitability for tea production in 2020 (Source: CIAT 2011)

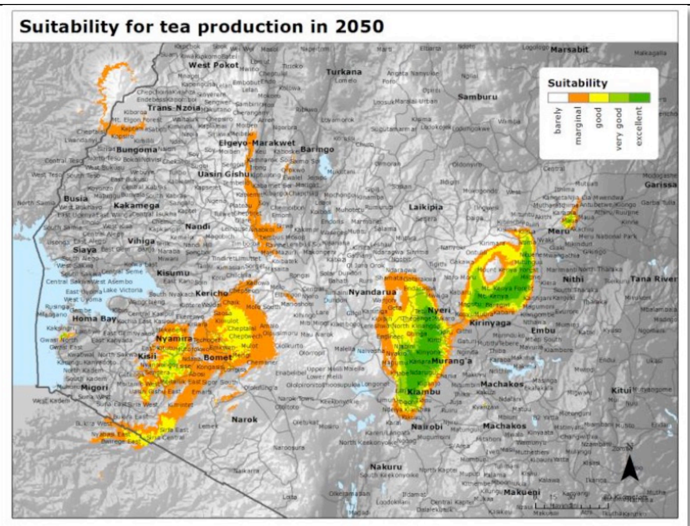


Figure 30c: Projected suitability for tea production in 2050 (Source: CIAT 2011)

Figure 30: Key results—tea

3.3 Crop Yield

The SRESA2a model estimates indicate that, throughout the tropical regions of the world, East Africa inclusive, without adaptation actions, maize productivity could decrease by 5–10 percent and rice productivity by 2–5 percent for every degree of warming (Knox et al. 2012; Figure 31). Knox et al. (2012) model projections show significant yield declines as result of climate change for maize (-5 percent), sorghum (-14.5 percent), and millet (-9.6 percent), while rice and cassava yields are projected to not be significantly affected. Total maize output is projected to decrease at a rate of 3–5 tons per decade from historical levels as a result of climate change. In the best scenario, with no adaptation, total maize production in the region would decrease from 42 to 37 million tons per year (12 percent), and in the worst-case scenario it could be as low as 25 million tons per year (40 percent reduction).

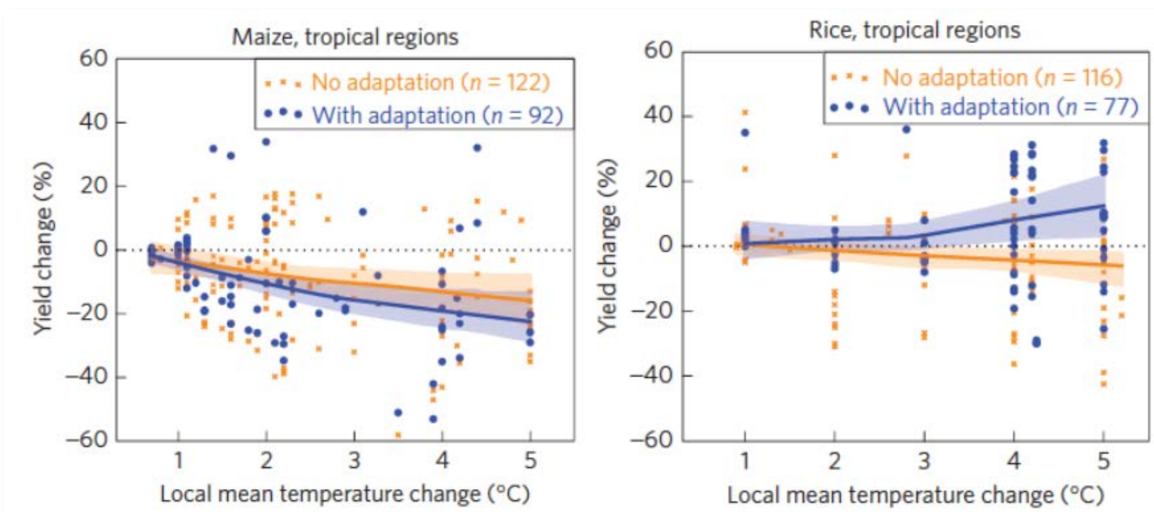


Figure 31: Changes in maize yield with changing climate (Ramirez-Villegas 2015)

3.4 SUITABILITY OF CROP LANDS

Relative to historical climate (1971–2000), these simulations indicate that impacts vary substantially by crop, with sorghum, cassava, yam, and pearl millet showing, on average, either little area loss or even gains in area in most regions (Figure 32). Conversely, common bean, maize, banana, and finger millet are projected to reduce their suitable areas significantly (30–50 percent) in many regions. Suitable area reductions for maize are less severe elsewhere, although Kenya shows some reduction. Most of these reductions result from temperatures that exceed the optimal and marginal maximum temperatures at which the crops can grow, and in a few cases (for pearl millet, sorghum, and yam) decreases in precipitation.

Suitability projections, however, also suggest that opportunities may arise from expanding cropping areas in certain countries and regions. A clear example of this is cassava, for which there could be opportunities beyond the geographical limits where it is currently cultivated, particularly toward higher elevation areas in East Africa (Figure 32).

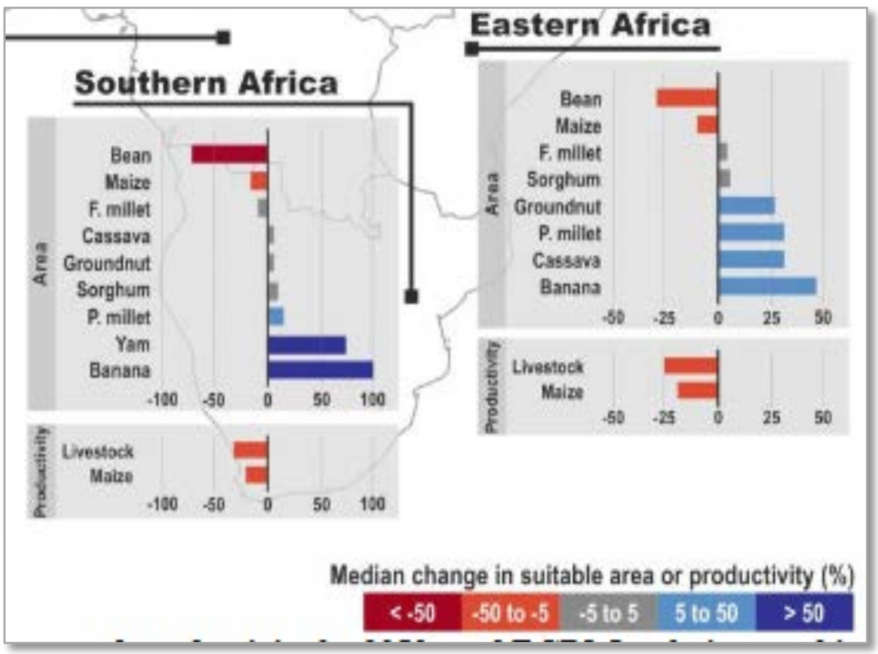


Figure 32: Projected median changes in climatically suitable area and productivity by 2050s and RCP8.5, relative to a historical period (1970–2000). Note: Median values are based on ensemble simulations of niche and productivity models and therefore should be interpreted in light of associated uncertainties. Livestock productivity refers to Annual Net Primary Productivity (ANPP) of rangelands (a proxy for livestock productivity), rather than to a direct measure of meat or milk productivity (Dinesh et al. 2015)

3.5 RANGELANDS

Simulations of the impacts of climate change on Africa's rangelands were based on the G-Range model. The G-Range is a moderate-complex model that simulates the growth of herbs, shrubs, and trees, and the change in the proportions of these plant types through time, as well as tracking changes in carbon and nitrogen in the soil and plant parts (Thorton et al. 2015). The death of plant parts, establishment and deaths of whole plants, livestock off-take, and fire, are simulated by this model (Thornton et al. 2015). From this simulation, future projected changes in the ANPP in Africa's rangelands during the present century are shown for two future emissions pathways:

intermediate (RCP4.5, blue) and high (RCP8.5, orange; Figures 33 a and b). It is established that ANPP and livestock production, productivity, and profitability are closely linked (Moore and Ghahramani 2013).

The spatial distribution of percentage change in ANPP production by the 2050s and RCP8.5 (high-end emissions) are known in relation to the baseline situation of 1971–1980. Changes in ANPP for RCP4.5 are relatively modest to the end of the century (~20 percent), with similarly modest changes in herb, shrub, and tree cover (in the range 10–24 percent, results not shown). In contrast, ANPP under RCP8.5 results in a 50 percent reduction in ANPP by the end of the century, caused for the most part by an 80 percent reduction in tree cover. Negative changes in ANPP by the 2050s under RCP8.5 are widespread throughout the continent's rangelands, with some positive percentage changes in pockets of central, eastern, and northern Africa (Figures 33a and b).

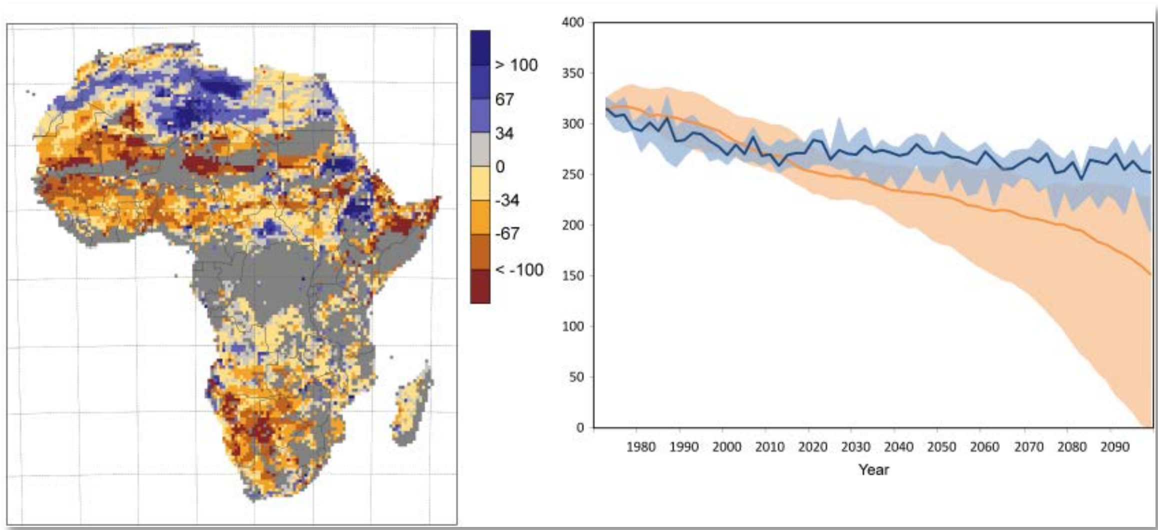


Figure 33: a) Projected changes in the ANPP of Africa's rangelands is a good proxy for livestock productivity. b) Future projected ANPP during the 21st century and two future emissions pathways: intermediate (RCP4.5, blue) and high-end (RCP8.5, orange); and (a) spatial distribution of percentage change in ANPP production by 2050s and RCP8.5 (high-end emissions) in relation to the mean value of 1971–1980. Source: Rosenzweig et al. 2014.

3.6 ANPP

Changes in ANPP in the rangeland areas of each country under RCP8.5 to the 2050s are shown in Table 12. Changes in the balance between herbs and shrubs could provide important insights into changes in suitability of the rangelands for different types of animals (e.g., browsers versus grazers). The results indicate that very substantial changes in livestock feed resources will occur during the century, and in large parts of the continent these changes will be detrimental. Many of these areas in the mixed crop-livestock systems will also see decreases in the quantity and quality of crop residues, putting further pressure on livestock feeding resources, reducing food security, and increasing the risk of hunger and under-nutrition for millions of livestock keepers, many of whom will have only limited capacity to adapt (Rojas-Downing 2015)

The possible effects of global change on food production are not limited to crops and agricultural production. Climate change will have far-reaching consequences for dairy, meat, poultry, and wool production mainly via impacts on grass and range productivity.

Table 12: Changes in ANPP in rangeland areas under RCP8.5 to the 2050s

Country	% Change in ANPP	
	Mean	Std
Kenya	-36.7	55.3
Rwanda	49.7	<0.1
Tanzania	-15.6	31.5
Uganda	-35.4	41.2

Table 13: Projected impacts for livestock in Africa under future scenarios (Niang et al. 2014)

Sub-region	Climate change impacts	Scenarios
Botswana	Cost of supplying water from boreholes could increase by 23 percent due to increased hours of plumping under drier and warmer conditions	A2, B2 2050
Lowlands of Africa	Reduced stoking of dairy cows, a shift from cattle to sheep and goats, due to high temperature	A2, B2 2050
Highlands of Africa	Livestock keeping could benefit from increased temperatures	A2, B2 2050
East Africa	Maize stover availability per head of cattle may decrease due to water scarcity	A2, B2 2050
South Africa	Dairy yields decrease by 10–25 percent	A2 2046–2065 and 2080–2100

3.7 LIVESTOCK PESTS AND DISEASES

Meta-analyses conducted by (Tomley and Shirley 2009) suggest that around 20 percent of ruminants (25 percent of young and 10 percent of adult animals) in Africa and more than 50 percent of poultry die prematurely each year; at least half of those deaths are due to infectious disease. Climate change can exacerbate disease in livestock. Among 65 animal diseases identified as most important to poor people, 58 percent are climate-sensitive (Thornton et al. 2014). In addition to these direct impacts, climate change may also have indirect effects on animal disease, such as:

- Increased rate of development of parasites and pathogens as a result of higher temperatures and greater humidity.
- Changed distribution and abundance of disease vectors.
- Exposure to new pathogens and vectors as a result of increased pest range.
- Altered ecosystem structure and function.
- Changes in peoples' behavior, which affect the exposure or vulnerability of animals.

There is clear evidence that some important livestock diseases, such as blue tongue, have already expanded because of climate change. Moreover, models predict changes in priority diseases such as trypanosomosis, which costs farmers in East Africa $2 billion a year; East Coast Fever, which kills one animal in Africa every 30 seconds; and RVF, which reduced exports from Africa by 75 percent.

Livestock diseases also have impacts on human health. Over 60 percent of human pathogens are zoonotic, or transmissible from animals, with a small number of zoonoses responsible for most illness. The most important are food-borne zoonoses, which causes billions of cases of illness. A World Bank study in 2012 estimates that over the past couple of decades, zoonotic diseases have had global costs of $6.7 billion per year. In low-income countries, zoonosis and diseases that recently emerged from animals, make up 26 percent of the infectious disease burden and 10 percent of the total human disease burden.

The Horn of Africa normally experiences heavy rainfall, particularly when there is a concomitant increase in the sea surface temperatures in the western Indian Ocean. There is strong association between El Niño and RVF risk (Anyamba et al. 2009). The recent predictions indicate the RVF will occur mostly in Kenya and Tanzania. In the LVB, the sections in Tanzania will be most affected (Figure 34).

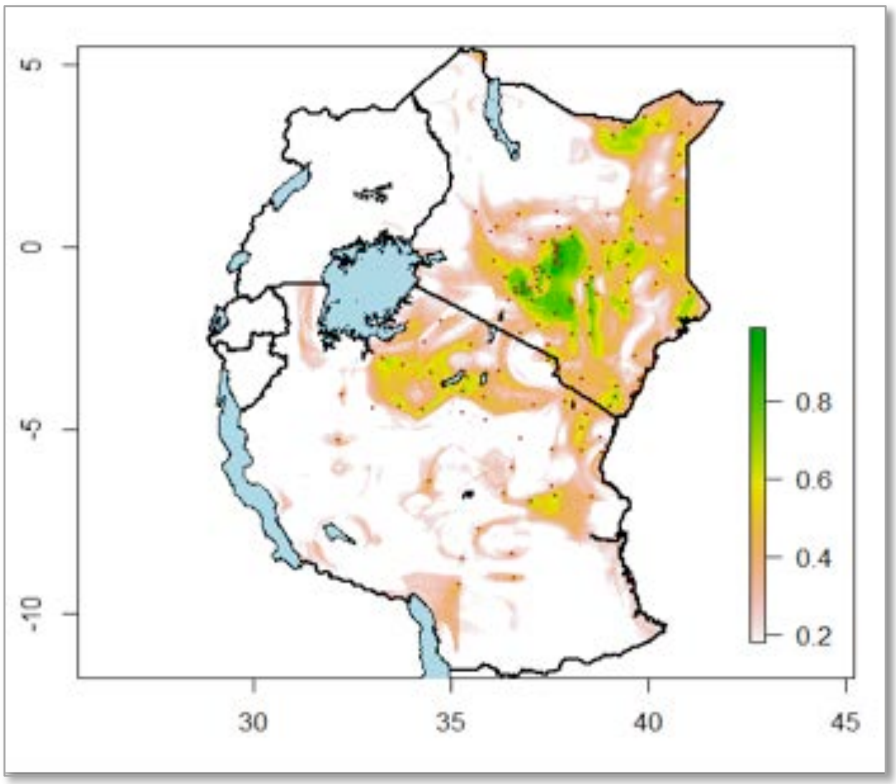


Figure 34: Prediction of RVF based on the El Niño signal in eastern Africa. Note: Red dots indicate areas that were affected during the 2006–2007 epidemics (source: Bett 2015)

3.8 Summary

A summary of projections on the sector and related studies is presented in Table 14.

Table 14: Projected impacts of climate change on crops, livestock, and fisheries in East Africa and the LVB

Issue(s)	Projected impacts
Climate changes in East Africa	❖ The projected changes in the annual rainfall component under each of the three different scenarios (RCP2.6, RCP4.5, and RCP8.5) and time windows (2030, 2050, and 2070) show relatively little change compared to the projected changes in the seasonal rainfall components. The short rains (OND period) are projected to increase over most of the region

Issue(s)	Projected impacts
	under all three scenarios (10–25 percent by 2030 and 25–50 percent by 2050). By contrast, the long rains (MAM period) are projected to decease over the northern part of the region but to increase over the southeast. The dry season rainfall (JJAS) is projected to decease over most of the region. The projected annual rainfall shows a tendency to increase over the LVB (CAMCO climate report 2016). ❖ Projected changes in the maximum temperature component for the three scenarios in the 2030s and 2050s periods compared to the reference period (1971–2000) indicate that by 2030, maximum temperatures during the long rains (MAM), the dry season (JJAS), and the annual component will likely increase by 1.0–2.0°C over most of the region (CAMCO 2016). The expected warming extent is greatest during the long rains (MAM) and the dry season (JJAS) and least during the short rains (OND). By 2050, annual maximum temperatures are expected to be 1.0–2.0°C higher under RCP2.6, 1.5–2.5°C higher under RCP4.5, and 2.5–3.5°C higher under RCP8.5 over most of the EAC, with slightly less warming expected in some coastal areas.
Food security	❖ Decline in long-cycle crops and rainfall between March to May (Funk et al. 2005, CAMCO 2016 climate report) ❖ El Niño events produce abnormally high amounts of precipitation in parts of equatorial East Africa and can result in flooding and decreased agricultural yields (IPCC 2001) ❖ Warming temperatures may negatively affect some fisheries in the region (Roessig et al. 2004) ❖ Warm temperatures may also lead to faster depletion of the limited oxygen supply, negatively affecting fisheries, and limiting lake overturn (Fick et al. 2005)
Extreme weather events	❖ Warming temperatures are projected to cause more frequent and more intense extreme weather events, such as heavy rain storms, flooding, fires, hurricanes, tropical storms, and El Niño events (IPCC 2001) ❖ The Horn of Africa normally experiences heavy rainfall, particularly when there is a concomitant increase in the sea surface temperatures in the western Indian Ocean. There is strong association between El Niño and RVF risk (Anyamba et al. 2009). And the impacts of RVF on livestock and humans can be devastating. In low-income countries, zoonosis and diseases which recently emerged from animals, make up 26 percent of the infectious disease burden and 10 percent of the total human disease burden (Mas-Coma et al. 2009, Mills et al. 2010) ❖ Increased rate of development of parasites and pathogens as a result of higher temperatures and greater humidity. Changed distribution and abundance of disease vectors and exposure to new pathogens and vectors as a result of increased pest range (Gornall et al. 2010) ❖ Lake levels in Lakes Victoria, Tanganyika, and Kivu have been attributed to climate variations and may become more variable in the future (Birkett et al. 1999) ❖ Climate change is projected to cause more frequent and intense El Niño Southern Oscillation events, leading to widespread drought in some areas and widespread flooding in others (Wara et al. 2005)

Issue(s)	Projected impacts
Maize	❖ The majority of currently cropped maize area in Africa is projected to experience negative impacts. Humid and West African countries are among the most negatively affected, with mean production losses between 20 and 40 percent by 2050s (RCP8.5), equivalent to 2°C above preindustrial temperatures (Ramirez-Villegas 2015). Crop yield losses in these areas will result from shortened cropping seasons and heat stress during the crop's reproductive period (Thornton et al. 2009). ❖ Recent impact studies on climate change on maize indicate an increase of maize yield with an increase in temperature up to 29°C followed by a sharp decline in yield with further temperature increases (Schlenker and Lobell 2010). ❖ Liu et al. (2008) reported the optimum maize-growing temperature to be 25°C. Each degree day above 30°C has been found to reduce maize yield by 1 percent even under optimal rain-fed conditions (Lobell et al. 2011). Another report suggests that a 1°C increase above norm reduces maize yield by 10 percent (Lobell et al. 2011). ❖ Local-level simulations based on the CERES maize model embedded in DSSAT v4.5 for East Africa using historical weather show yield variability from 45 percent in a dry site to 21 percent coefficient of variation in a wet site (Alagarswamy et al. 2015). Water deficit levels in much of Uganda and south-central Tanzania worsen as precipitation declines and temperatures increase. In general projected future warming led to a reduction in the length of growing season with decreases in maize yields in central Uganda, coastal Kenya, and eastern sections of Tanzania. In Rwanda and Burundi the projection are mixed in some areas with observed potential for increases or declines. Based on large variability and heterogeneous landscapes the changes in maize production varied between -3,000 to +3,000 kilograms per hectare (Alagarswamy et al. 2015). Unfortunately, the yield declines are in major producing zones of East Africa ,raising serious concerns about food security in the region.
Rice	❖ Rice is a C3 crop and is expected to benefit from increased atmospheric CO_2 concentrations. However, increases in temperature have the potential to negate any benefit of elevated CO_2 in rice yield (Ainsworth 2008). Projections of the impact of climate change on rice in the region vary. Lobell et al. (2008) used 20 GCM models and projected a slight increase (<5 percent) in rice production in East Africa by 2030 compared to 1998–2002. Other studies using the Impact model found a 0.24 percent increase in rice yield in eastern Africa and a 2.32 percent reduction in southern Africa by 2050 (Ainsworth 2008, Conway 2009).
Cassava	❖ Cassava is known to be resilient to climate change due to its tolerance of high temperatures and intra-seasonal drought (Jarvis et al. 2012). However, if a prolonged drought period (>2 months) falls during the root thickening initiation state, a root yield reduction of up to 60 percent may occur (Jarvis et al. 2012). Cassava shows better yield gain than grain crops at higher CO_2 concentrations, can recover from very long drought periods, and exhibits increases in optimum growth temperature under elevated CO_2 levels (Rosenthal and Ort 2012). These qualities make cassava a suitable crop in a future that is projected

Issue(s)	Projected impacts
	to experience elevated CO_2, increased temperature, and variable rainfall patterns.
Coffee	❖ Recent studies by Bunn et al. (2015) indicate highly negative impacts of climate change on arabica coffee, with more 50 percent of areas in Uganda and Tanzania disappearing, 20–50 percent of areas in Burundi and Rwanda reducing significantly, and less significant (but still noticeable) negative effects on Kenya. For robusta coffee, models indicate that two East African countries might experience substantially negative impacts: Uganda and Tanzania, whole Burundi, Kenya, and Rwanda are more likely to experience gains in robusta-suitable areas. ❖ According to the ARIMA model (autoregressive integrated moving average), average coffee production will drop to145±41kgha−1 (P<0.0001) by2060 (Craparo et al., 2015). ❖ In Uganda, the total area suitable for growing robusta coffee would be dramatically reduced with a temperature increase of 20°C. Only higher areas would remain, the rest would become too hot to grow coffee (UNEP report).
Crop suitability	❖ Simulation of the impact of climate change on crop land suitability in eastern Africa indicates that relative to historical climate (1971–2000), impacts vary substantially by crop, with sorghum, cassava, yam, and pearl millet showing, on average, either little area loss or even gains in area in most regions (30–50 percent; Ramirez-Villegas and Thornton 2015). Conversely, common bean, maize, banana, and finger millet are projected to reduce their suitable areas significantly (20–50 percent) in many regions (Dinesh et al. 2015, Ramirez-Villegas and Thornton 2015).

4. SECTOR ADAPTATION PRACTICES, OPTIONS, AND CONSTRAINTS

4.1 KEY CONSIDERATIONS

Human populations are vulnerable to the impacts of climate change largely because of the socioeconomic and political context in which they live. Thus, vulnerability to climate change is highly differentiated across geography, income levels, type of livelihood and governance arrangements (O'Brien et al. 2007). Human vulnerability can be evaluated in terms of a range of different outcomes such as food security or household income. Areas vulnerable to disasters are not necessarily the same as those where food availability is likely to be negatively affected by climatic changes. A major challenge in viewing human vulnerability as the result of multiple and dynamic factors is the need to take a synthetic approach to translate sectoral impacts of climate change and variability into consequences for people. For example, East Africa is already a recipient of food aid. Under many scenarios, the number of food insecure people in East Africa by 2020 is likely to double, a challenge that will clearly not be made any easier by increases in rainfall and temperature variability. These increases could be particularly large in the LVB due to high population growth rates and relatively large areas with high rainfall variability.

The countries of East Africa have among the highest population growth rates in the world and endemic poverty affects more than 50 percent of the region's 360 million people (Thorn et al. 2015). Between 1988 and 2008 the region's population increased by a staggering 74 percent; it may double by 2050. While urbanization and industrial development is growing across the region, agriculture will continue to dominate the countries' economies. Climate change therefore will only complicate the existing challenges of socioeconomic development. Coping strategies and adaptation measures are essential, including the introduction of new crop varieties, better land management, and farmers synchronizing with new seasons. Recent trends and the current performance of agriculture expose the region that is progressively less able to meet the needs of its burgeoning population.

Climate change will have far-reaching consequences for poor and marginalized groups, the majority of whom depend on agriculture for their livelihood (Nicholson 2015). Agriculture accounts for more than 40 percent of GDP across East Africa. However this is being compromised by challenges related to ecosystems degradation, poor infrastructure, limited reliable information, and poor policy coordination (Nicholson 2015). Meanwhile weather systems are becoming more erratic and violent. Given their low capacity to adapt, poor and marginalized groups are likely to become more desperate, threatening their very survival under the changing scenarios of climate change.

For example, the vulnerability of fisheries and fishing communities depends on their exposure and sensitivity to change, but also on the ability of individuals or systems to anticipate and adapt. This adaptive capacity relies on various assets and can be constrained by culture or marginalization. Vulnerability varies between countries and communities, and between demographic groups within society. Generally, poorer and less empowered countries and individuals are more vulnerable to climate impacts, and the vulnerability of fisheries is likely to be higher where they already suffer from overexploitation or overcapacity.

Compared to Asia which accounts for more than 90 percent of global aquaculture production, aquaculture is in its infancy on the African continent, but has huge potential to expand and contribute to food and nutritional security in the region. Aquaculture operations in the tropics experience higher cumulative mortalities and faster progression of diseases. This could be exacerbated by climate change. Water-borne pathogens have the potential to spread at faster rates than in terrestrial systems. Extreme weather events and international trade (especially trade in live aquatic animals) have the potential to transmit disease across wide geographies. Reports of two major climate-sensitive diseases—epizootic ulcerative syndrome (EUS) in fishes since 2007 in Botswana, Namibia, and Zambia and shrimp white spot disease since 2011 in Mozambique—are examples of how pathogens can jump national and international boundaries and bring about devastating impacts on communities. EUS occurs in natural freshwater systems and extreme weather events like flooding can distribute EUS over thousands of kilometers.

It has been observed that national programs and interventions that are not complemented by locally relevant and tested adaptive strategies are unlikely to produce useful outcomes for most farming communities. Apparently, adaptive strategies developed at national scales might not be locally appropriate, particularly when climate impacts and adaptation responses are local (i.e., influenced by ecosystems and social and cultural relations unique to an area). Findings occasioned by this assessment indicate that while adaptation occurs farm by farm, the identification and dissemination of adaptation options—and enabling of their adoption—requires a national effort.

Local communities have developed some coping strategies to avoid or recover from the impact of climate change and variability. A variety of institutions and policy frameworks have been put in place at the regional and national levels to support adaptation to current and future impacts of climate change. Communities have local coping strategies and, at the national level, governments have adaptation plans of action, strategies, and policies relevant to the sector. The EAC similarly has regional strategies and policies governing collective efforts to curb the impact of climate change in the region with major goals of food security and poverty alleviation

Although some adaptations and adaptation policies are short term and require more immediate action, other policies and practices will yield adaptive benefits over the long term. These geographic and time-scale considerations led the assessment team to identify specific recommendations, which are summarized below according to activity focus: establishing the national context for adaptive agriculture, expanding research and learning across stakeholder groups, and strengthening and diversifying livelihoods.

An analysis of practices, options, and constraints in East Africa is summarized in Table 15. The impact of increased climate variability and change on crops is highly significant in the region and various adaptation and mitigation efforts are needed.

Table 15: Summary of context for the agriculture sector in the EAC

	Burundi	Kenya	Tanzania	Uganda	Rwanda
Agri-export sector	❖ 34% of GDP; 90% of livelihoods depend on agriculture	❖ 29% of GDP; 80% of livelihoods depend on agriculture; accounts for over 65% of Kenya's total exports; provides 18% of formal and 60% of total employment	❖ 25% of GDP; 77.5% of livelihoods depend on agriculture	❖ US$1.1 billion (2011) 71% land under agriculture 23% of GDP 80% of livelihoods depend on agriculture	❖ 88.6 million hectares of land suitable for agricultural production, including 60 million hectares of rangelands suitable for livestock grazing, 32% of GDP; 86.5% of livelihoods depend on agriculture
Key agri-exports	❖ Coffee ❖ Tea ❖ Cotton ❖ Oil palm	❖ Coffee ❖ Tea ❖ Horticultural crops (especially flowers and fruits)	❖ Coffee ❖ Cashew nut ❖ Tea ❖ Cotton ❖ Tobacco ❖ Sisal	❖ Coffee ❖ Tea ❖ Cotton ❖ Tobacco ❖ Fishery products ❖ Cereals (especially rice, beans, and maize)	❖ Horticultural crops ❖ Tea ❖ Coffee
Climate impacts	❖ Rainfall deficits have led to aggravated aridity, significant reduction of principal wetlands and drying up of several rivers and lakes with a consequent decrease in agricultural production, increase in morbidity and mortality among humans and livestock, repetitive floods, landslides, loss of biodiversity, etc.	❖ The frequency and severity of droughts and floods have continued to increase because evaporation rates and rainfall intensity have also increased	❖ The frequency of extreme weather events such as El Niño floods in 1997/98 and the recent drought are few but important reminders of the deadly effects of climate change	❖ Past floods and droughts have already led to decreased water availability and production and revenue losses due to crop and infrastructure damage. A lot of uncertainties exist due to limited availability of data and analysis	❖ Floods, landslides, and droughts constitute the major repetitive natural disasters associated with climate change often linked with ENSO episodes
Adaptation responses	❖ Adaptation of the agricultural calendar to the changing cycles of seasons	❖ Changes in land use or activities, changes of location ❖ Restoration of degraded ecosystems	❖ Promotion of alternative farming systems ❖ Promotion of proper agronomic	❖ Export diversification and value-chain approach, although explicit	❖ The National Adaptation Program of Action has been designed to implement projects aimed at fighting prolonged drought risks in

	Burundi	Kenya	Tanzania	Uganda	Rwanda
	❖ Introduction and adoption of improved species ❖ Replacement of cattle by small ruminants ❖ Conservation of genetic resources, etc. ❖ Integrated management of water resources ❖ Promotion of bridging crops resistant to long dryness ❖ Promotion of fast-growing crop species ❖ Research on local and exotic animal species resilient to climate change ❖ Promote the techniques of conservation of food and the fodder banks	❖ Provision of downscaled weather information and farm inputs ❖ Investments in water resources management for irrigation ❖ Sustainable utilization and management of natural resource base (soil and water conservation techniques) ❖ Research and dissemination of superior (drought-tolerant, salt-tolerant, pest- and disease-resistant) crop and livestock breeds ❖ Diversification of rural economies as a way to spread risk	management practices ❖ Increased investments in water harvesting and conservation for crop production ❖ Promotion of short-season and drought-resilient crops such as sorghum and millet ❖ Matching crop production with agro-ecological zone suitability ❖ Integrated crop and pest management ❖ Strengthen early warning system ❖ Make better use of climate and weather data, weather forecasts, and other management tools ❖ Creation of awareness of the effects of climate change ❖ Investments in natural resource management, community-based catchments conservation, rangeland	mainstreaming of climate risk is lacking	eastern and southern provinces and risks of intense precipitation and erosion in the northern and western provinces

	Burundi	Kenya	Tanzania	Uganda	Rwanda
			management, and afforestation		
Elements of adaptive capacity	❖ To spur adaptation, the country aims to regularly provide agricultural inputs at affordable prices; promote commercial farming, agro-processing, and value addition. In the livestock sector, the country aims to intensify artificial insemination	❖ Improvement of sustainable land use	❖ Promotion of small-scale irrigation ❖ R&D on drought-resilient seed and livestock ❖ Enhancing capacity of agriculture extension activities ❖ Promotion of diversification of agriculture: growing different types of crops on different land units ❖ Water harvesting	❖ Strong focus on diversification of exports and export markets ❖ Growing awareness of climate risk at the national level ❖ Low competitiveness and weak business environment ❖ Landlocked country with weak transport links ❖ High production costs (inputs, energy, storage, etc.) ❖ Limited research capacity	❖ Focus is on promotion of non-rain-fed agriculture ❖ Increase agricultural techniques ❖ Introduction of species resistant to drought in arid and semi-arid zones ❖ Proper post-harvest handling ❖ Reinforce early warning and rapid intervention systems ❖ Reinforce animal husbandry in permanent stalling
References	❖ Republic of Burundi 2007 (NAPA)	❖ Republic of Kenya 2010 national climate change response strategy (NCCRS); NCCAP 2013	❖ United Republic of Tanzania 2007 (NAPA)	❖ Adapted and modified from Kasterine et al. 2015 ❖ National Development Plan and Export Strategy	❖ Republic of Rwanda 2006 (NAPA)

4.2 INSTITUTIONAL AND POLICY FRAMEWORK—SECTOR PREPAREDNESS

Various policy, institutional, and legal frameworks have been developed in the East African region to address adaptation to climate change. Policies, laws, and frameworks also guide agriculture production systems and food security throughout the region. At the regional level, these include:

- Agriculture and rural development policy and strategy for the EAC (2006)
- East African Community Climate Change Policy (EACCCP) (2007)
- The International Food Policy Research Institute (IFPRI) strategy on climate change
- Consultative Group on International Agricultural Research (CGIAR) – Climate Change Agriculture and Food Security Programme
- Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) – climate change strategy
- NEPAD – Comprehensive Africa Agriculture Development Programme (CAADP) strategy

Cognizant of the importance of agriculture, the EAC CAADP Compact was developed in line with the objectives of the EAC Treaty, and operationalized through the EAC Agricultural Rural Development Policy (ARDP), EAC Agricultural Rural Development Strategy (ARDS), and the EAC Food Security Action Plan (FSAP). The Compact sets the parameters for long-term partnership in the agricultural sector, specifies key commitments of the African Union/NEPAD, EAC Secretariat, Partner States, development partners, private sector, farmer organizations and cooperatives, civil society organizations, nongovernmental organizations (NGOs), and institutions of higher learning and research. It also defines expectations from all stakeholders on their investments and contributions toward successful implementation of the FSAP and Climate Change Policy and Master Plan.

The Compact contains sector policies, investment niches, and stakeholder commitments to align long-term development goals with agricultural sector programs. It also supports the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods. The Compact provides a commitment framework for transforming crops, livestock, capture fisheries and aquaculture, apiculture, wildlife, and forestry through opportunities for inclusive growth and sustainable development.

Since agriculture is the most vulnerable sector and a major livelihood option for majority of the region's population, it is necessary to develop and implement location and context-specific plans for action. Enhancing the adaptive capacity and resilience of climate-vulnerable communities, requires the active participation and ownership of local communities in local adaptation planning. To achieve this goal, EAC countries have prepared National Adaptation Programs of Action (NAPAs), which were endorsed by their respective governments for implementation, and are tailored to implement prioritized areas of intervention in each country, except Kenya. Kenya developed the National Climate Change Action Plan instead since it was not considered a least developed country.

Broad agricultural adaptation strategies in East Africa (as synthesized from the East African counties' NAPA, NCCRS, NCCAP, and EAC Climate Action Plan documents) are summarized below.

- **Improvement of agronomic management**. In East Africa, farm yield gaps tend to be very large. This necessitates improvement of agronomic management and input use efficiency. Climate information that reduces farmers' uncertainty during a given season has potential to improve the effectiveness of production technologies and input use efficiency. Reducing uncertainty enables farmers to adopt improved technology, intensify production during better years, and reduce risks during bad years. Climate information services enable farmers to adopt new technology and thus sustainable intensification of production by understanding spatial and temporal climate variability.

- **Environmental conservation**. This focuses on efforts geared toward the sustainable use of water, land, soils, forests, and marine resources. Use or misuse of these resources can have a negative or positive impact on the agricultural sector. For example, the encroachment of agriculture on forestry resources affects not only the immediate forest but also alters the hydrological cycle. This in turn affects agricultural production initiatives downstream. Agriculture solely depends on the integrity of the natural ecosystem. Some adaptive actions include agroforestry; soil and water conservation; reforestation; water harvesting; soil and plant nutrient management; grazing management, and others.

- **Dissemination of climate information**. Advances in climate prediction and analysis, as well as synthesis of climate knowledge, have the potential to enhance livelihood opportunities in agriculture (Selvaraju, Gommes, and Bernardi 2011). This is important in risk management and sustainable production. The climate information and likely decisions are: (i) climate change scenario to understand the trend and alter system-level decisions (cropping or grazing); (ii) seasonal climate information to make strategic decisions (crop type, marketing, forward selling, livestock herding rate, etc.); (iii) intra-seasonal forecasts to schedule tactical operations (fertilizer, water, and other adjustable inputs); and (iv) weather forecasts for day-to-day operations.

- **Crop monitoring and yield forecasting.** Analysis of meteorological and climatic data allows the provision of near-real-time information about crop status, with the possibility of early warning for risks. Crop monitoring and yield forecasting allow timely interventions by the government to avoid crises. The strategies include contingency plans, alternate livelihood options, and response plans for food aid. Large-scale monitoring of agriculture and crop yield forecasting generally rely on: (i) regionalized analyses of cultivated areas, crop type distribution, and crop condition based on near-real-time satellite imagery merged with available in situ observations; (ii) meteorological monitoring and mid-term forecasts based on observation networks and model outputs; and (iii) regionalized knowledge of agricultural systems and their sensitivity to meteorological conditions. The crop monitoring and yield forecasting capabilities in East African countries are weak and need strengthening at the national level with more emphasis on collection of data such as meteorological, agro-meteorological, soil, pest and diseases, remote sensing, and agricultural statistics.

- **Agricultural insurance.** Index-based insurance products for agriculture are an attractive alternative for managing weather and climate risks (Skees 2008). Agricultural insurance is growing as a result of increased commercialism and availability of new types of insurance products. For the government, insurance mechanisms provide a measure of predictability for weather risk financing and offer enough lead time for emergency responses to manage livelihood crises. This lessens the weather/climate effects by securing needed resources sooner to protect livelihoods. Provision of localized and needs-based climate information to promote index-based weather insurance requires strengthening of weather observation networks, monitoring of extreme climate events, standardization of indices, data sharing, early warning systems, and capacity building. The index-based weather insurance systems require the support of national meteorological and hydrological services to ensure high-quality weather data, monitoring instruments, and procedures to downscale weather information to produce real-time crop yield indices covering specific agro-ecological regions.

- **Strengthening technical and institutional capacities.** Strengthening the capacity for agrometeorological observation, development of customized forecasting products, management of data and modelling for climate impact assessment, application of climate information at the farm level, and strengthening of decision-support systems at the institutional level are a priority (NCCAP 2013, NCCRS 2012, Selvaraju et al. 2011). Agricultural extension services need to be strengthened to address climate risks and plan for adaptation if these are to provide an efficient interface between policymakers and farming communities. Strengthening of community networks, local institutions, and norms and relationships is critical for managing climate risks. Local networks shape the farmers' social interactions leading to better participatory decisions.

- **Strengthening seed systems.** Seeds are a core resource of crop production systems and carry the genetic potential for crop adaptation to changing environments. Increased abiotic and biotic stresses will directly impact food production. The system that will provide adapted varieties to farmers has three parts: plant genetic resource conservation and distribution, variety development, and seed production and delivery. The stronger the links among these different parts, the better the whole system will function.

  a. Conserved and improved materials need to be available for a diverse portfolio of varietal development that will meet changing demands and requirements.

  b. Timely delivery to farmers of suitably adapted materials, of the right quality and quantity, at an acceptable cost, is essential.

  c. The system needs an appropriate institutional framework as well as policies and practices that support its component parts and the links between them. The time required for developing and releasing new varieties is lengthy compared with the pace of environmental changes under pressure from increased climate variability and change. Urgent action is needed to ensure that a local genetic resource base, adequate capacities, and effective collaboration among policy, research, and users are available to face new needs.

  d. Intensification of the conservation of plant genetic resources in situ and ex situ, since the survival of the wild relatives of crops (an important source of genetic diversity for crop improvement) could be threatened.

  e. Discrepancies among seed regulations remain a barrier to seed trade and exchange of varieties in East Africa. Facilitating seed exchange among countries will be necessary to cope with seed shortages. Harmonization of seed regulatory frameworks is key to ease administrative procedures for cross-border seed trade. At the same time, the establishment of regional variety release procedures and variety catalogs will bring access to a wider diversity of varieties with the potential to adapt to climatic changes.

  f. Agricultural diversification, crop and variety relocation based on mapping agro-ecological zones, and variety characterization will be necessary to provide farmers with the germplasm (landraces and modern varieties) adapted to shifting agro-ecologies. Improved ways of transmitting information about crop variety adaptation through market and non-market channels are also needed.

- **Capacity building/skill development.** In the past, rural communities have always worked to adapt to changes in climate as they gradually occurred over centuries, but now changes appear to be faster and more dramatic. Therefore, farmers would benefit highly from support to help develop sound and location-specific adaptation strategies. Farmers with knowledge of local ecosystems, and with critical thinking skills, would stand a much better chance of coping with the effects of climate change. Enhanced skills might not only help to reduce vulnerability in future generations but also imply higher human capital. This will be helpful in reducing vulnerability in post-disaster situations. Theoretically a population that is skillful is more likely to be resilient due to their ability to draw on alternative entitlements in the face of a shock.

Tables 16 and 17 summarize sector preparedness by country.

Table 16: Reflection in NAPA on agriculture sector within East African countries

Country	Proposed adaptation options
Burundi	1. Improve seasonal early warning climate forecasts 2. Popularize rainwater harvesting techniques for agricultural or domestic use 3. Set up erosion control mechanisms in sensitive areas 4. Identify and popularize dryness-resistant forest species 5. Popularize short-cycle and dryness-resistant food crops 6. Popularize zero grazing techniques 7. Train and inform decision makers and other partners, including local communities, on methods of adaptation to climate variability 8. Identify and popularize the breeding of species adapted to local climate conditions
Tanzania	1. Promote indigenous knowledge 2. Change planting dates in some agro-ecological zones 3. Increase irrigation to boost maize production in selected areas 4. Introduce or expand drip irrigation for specific regions 5. Reduce reliance on maize as staple food by growing short-season and drought-tolerant crops such as sorghum and millet 6. Shift crop farming to more appropriate agro-ecological zones 7. Change crop rotation practices 8. Introduce or expand integrated crop management 9. Make better use of climate and weather data, weather forecasts, other management tools 10. Create awareness of the negative effects of climate change 11. Introduce or expand sustainable water management to boost food crop production 12. Strengthen early warning system 13. Follow standard agronomic practices 14. Promote annual and short-term crops 15. Change land use patterns 16. Control tsetse fly 17. Introduce or expand integrated pest and disease control 18. Introduce or expand sustainable range management 19. Conduct relevant research and development 20. Educate farmers and livestock keepers 21. Advocate zero grazing 22. Control movement of livestock
Rwanda	1. Promote non-rain-fed agriculture 2. Increase agricultural techniques 3. Introduce species resistant to drought in arid and semi-arid zones 4. Introduce precocious varieties in arid and semi-arid zones 5. Promote stocking techniques of agricultural products after harvesting 6. Reinforce early warning and rapid intervention systems

Country	Proposed adaptation options
	7. Reinforce animal husbandry in permanent stalling 8. Promote veterinary and phytosanitary services 9. Prepare and implement land development plan 10. Introduce or expand integrated water resources management, including for rainwater 11. Promote non-agricultural activities 12. Prevent and fight against vectors of water-borne diseases 13. Integrate NAPA in policies and national development plans
Uganda	1. Exploit aquatic resources 2. Invest in post-harvest management, e.g., food preservation 3. Promote alternative livelihood systems 4. Promote under-utilized and non-conventional foodstuffs 5. Increase investments in natural resource conservation, e.g., water harvesting and soil conservation 6. Promote sustainable agricultural practices, e.g., change in husbandry practices 7. Promote traditional vector control 8. Promote appropriate indigenous knowledge, e.g., indigenous approaches to rainmaking and thunderstorm prevention 9. Strengthen legal and policy coordination and enforcement 10. Develop and communicate hygiene and sanitation strategies 11. Strengthen early warning and early action systems, e.g., strengthen district disaster management committees 12. Renting land bush burning

Table 17: Excerpts from the Kenya National Climate Change Action Plan

1. Coordination and mainstreaming of climate change into agricultural extension
2. Establishment and maintenance of climate change–related information for agriculture
3. Up-scaling specific adaptation actions—Promotion and bulking of drought-tolerant traditional high-value crops
4. Water harvesting for crop production
5. Index-based weather insurance
6. Conservation agriculture
7. Agro-forestry
8. Integrated soil fertility management.
9. Promote climate-smart agriculture in Kenya
10. Development and application of Performance Benefit Measurement methodologies for adaptation, mitigation, and development
11. Livestock grazing management systems, fodder banks, and strategic reserves
12. Price stabilization schemes and strategic livestock–based food reserves
13. Selection and breeding animals to adapt to climate change
14. Livelihood diversification (camels, indigenous poultry, beekeeping, rabbits, emerging livestock, such as quails, guinea fowls, ostriches, etc.)
15. Capacity building—Inventory of indigenous knowledge, livestock insurance schemes, early warning systems, early action, stocking rates, vaccination campaigns, disease control

However, uncertainties about the pace and extent of climate change and the impacts on different sub-regions and sectors in the LVB make policy decisions difficult, and magnify the need for the region to improve its knowledge and analytical base. While national-level information and analysis on climate change risks, vulnerability, and impacts has improved substantially over the past decade, well-synthesized information and an established knowledge base, at a basin, sub-basin, or even national level, is often absent. This is particularly critical to decision-making processes, providing policy guidance and considering transboundary responses to climate change. Some key opportunities include:

- Mainstreaming/integrating climate change and climate change adaptation in National Poverty Reduction Strategies, National Development Plans, and other economic plans;
- Implementation of the Maputo Declaration to achieve 6 percent growth in the agricultural sector;
- Building platforms and cooperation and coordination mechanisms to make sure that synergies in programs and initiatives are adequately used and activities are coordinated to maximize the related outcomes and benefits; and
- Enhancing functional capacities to access international and national climate change funds and increase additional private contributions and improve investment conditions in target countries.

4.3 GENDER CONSIDERATIONS

Climate change will affect women, men, and youth differently and will widen the gender gap in the communities of the LVB. Adult women and youth (male and female) are the two groups most affected by poverty. This is because women, men, and youth play different and complementary roles, experience different resources availability, and have different responsibilities with for agriculture and food security. Gender impacts will vary according to age, sex, income group and geographical location. Climate change impacts have the potential to wipe out progress that has been achieved in relation to gender equality. Youth living around the LVB are affected by climate change and variability, poverty, and unemployment leading to rural-urban migration. Agricultural activities can provide a source of livelihood opportunities for youth. At the same time, youth may more readily adapt to climate change because they stand to inherit the full burden of climate change impacts.

Pearson et al. (2013) explores the experiences of women who live at five fish-landing sites on Lake Victoria, Uganda. Their intention was to explore the economic and social opportunities available to women to try to understand why some women are more vulnerable to violence and other risks than others and why some women are able to create successful enterprises while others struggle to make a living. Pearson et al. (2013) notes that most women lack economic opportunities at fish-landing sites, which tend to make them very vulnerable. Their research reveals that women's inaccessibility to capital and credit facilities to get started in business forces them to establish sexual relationships to get support. They are exposed to lower pay and more risky work such as fish processing and selling or working in bars.

In the Lake Victoria region, men predominantly engage in fishing, own or lease boats and gear, and retain profits from fish sales. Most men are ignorant of their duty to contribute money for regular purchases like food and cooking gas, unlike women who engage their efforts in providing for their children. Fish export factories are more inclined to advance men lines of credit to allow the fishermen to buy equipment and boats. Men are then obliged to sell their fish directly to the factories and not to women in the community as had historically been the case. Consequently, women can barely support themselves.

Plate 2: Women engage in risky, low paying work

Plate 3: Male youths engage in fishing and fish processing activities

Women pastoralists are vulnerable to climate change in the LVB for several reasons: cultural restrictions, poverty, conflicts, unfavorable government policies for the ASALs, and national legal frameworks over the years have not promoted women's participation in decision making (FAO 2003 and Government of Kenya 2004). Empirical research has shown that there is poverty differentiation between households headed by women and those headed by men. Women-headed households are likely to be poorer than those headed by men (Omolo 2010). But Buvinic (1993 cited in Appeleton 1996:1819) argues that not all households headed by women are more vulnerable than those headed by men and it is important to disaggregate data according to different types of women-headed households. This is because households headed by widows are more likely to be vulnerable than those headed by married women, which are likely to be more prosperous.

Plate 4: Women participating in various community activities

Women remain overburdened with reproductive roles at household levels. These activities reduce the time available to them to participate in leadership activities within the community. (Brody et al. 2008). In pastoralist areas, where men are traditionally responsible for livestock, reduced herd sizes due to drought has forced men to migrate to urban centers for wage-employment, which imposes additional burdens on women and children to sustain household food, water, and security. Male youth are under pressure to demonstrate strength as warriors and find ways to pay high bride prices, increasing the likelihood of joining cattle raids or armed conflict, while female youth are susceptible to violence associated with cattle raids and armed conflict (International Youth Foundation 2011).

Plate 5: Effects of drought in pastoralist areas

Women constitute a large proportion of the agricultural labor force and depend heavily on agriculture for their livelihoods in the LVB. Despite this, they have an average of 20–30 percent lower productivity than men, which is attributed to differences in input levels. Youth meanwhile, constitute more than 60 percent of the population in most countries in the LVB and have high rates of unemployment.

Plate 6: Woman irrigating *Sukuma wiki* and youths carrying out land reclamation

Agriculture in the lake region has been devastated by crop diseases. Women have to work longer hours to expand acreage or earn cash from casual labor or both. They also get involved in activities such as brewing and petty trade to earn income for family and personal use. Although there are opportunities in agriculture and agribusiness, youth often do not have the necessary skills or access to resources to enable them to earn a living from the agricultural sector, either through employment or by starting their own businesses (Rugalema and Mathieson 2009).

The sector has remained unattractive to young women and men for several reasons:

- Low returns on time and input investments
- Seasonality of incomes
- Lack of education/knowledge of modern farming and marketing approaches
- Risks due to unpredictable weather and other natural factors such as pests
- Lack of innovations leading to reliance on traditional labor-based production techniques
- Concentration on a narrow range of agricultural commodities mainly staple crops
- Limited access to land among the youth and women
- Low investments in the infrastructure necessary for efficient value chains, such as roads, hubs for produce consolidation, and cooler houses.
- Planning for climate change adaptation has been facilitated through development of NAPAs. Burundi, Rwanda, Tanzania, and Uganda have prepared NAPAs detailing priorities, projects, and policies intended to reduce national vulnerability and build adaptive capacity to the impacts of climate change. Kenya has detailed similar aims in its NCCRS (2010). All of the documents have prioritized agriculture.
- The Burundi NAPA (2007) aims to evaluate the vulnerability of the country and put forward priority measures and activities to reduce the adverse effects of climate change and apply forecast policies to be able to react to future disasters. It provides for the consideration of women in the selection criteria of priority options. The criterion, which is based on several factors, must also consider the need to empower and reduce poverty among women. There is no specific provision for youth.
- The Kenya NCCRS (2010) recognizes that climate change has the greatest effect on the poor, who are mostly women and children. Women in Kenya have been disproportionately affected by drought due to pre-existing gender discrimination that exposes them to higher rates of poverty and insecurity. The NCCRS seeks to raise public awareness through the formation of groups for youth and women and the inclusion of existing youth groups and initiatives in ongoing climate change and decision-making activities. It ensures and encourages equal representation of men and women in technology development, training, and transfer. It also proposes development of a "Trees for Jobs" program to create employment for youth. The Kenya Strategy is more comprehensive than other countries' NAPAs and has addressed gender-related initiatives in a bid to improve livelihoods.
- The Rwanda NAPA (2006) has been formulated to establish criteria for secure settlements in areas exposed to meteorological hazards. It also proposes to develop and implement an early warning system for drought and food security to protect the population exposed to food insecurity and maintain food supply and the capacity of the population to acquire food. It establishes criteria for looking after the displaced population after a catastrophe and institutionalizes the functions of catastrophe management at all levels. The NAPA also proposes preparation of a continuous program of mobilizing public action using available media. No specific provision caters to women and youth.

- The Tanzanian NAPA enunciates problems faced by women and children, such their higher vulnerability to malaria and cholera than men and lack of water, which typically requires women and children, especially girls, to travel long distances in search of water. The plan seeks to improve the livelihoods of Tanzanians by improving the participation of women and youth groups in the restoration of degraded areas around Mount Kilimanjaro and in tree planting. The expected outcome of the plan is to build their capacity on climate change adaptation and biodiversity conservation with a special focus on conservation of damaged river valleys.
- The Uganda NAPA (2007) recognizes the differential effect of climate change on men, women, and youth. Because women have an important role in looking after the households, they spend long hours during drought in search of water and firewood, depriving them of time for other productive economic activities. During floods, when water and sanitation-related diseases are more prevalent, they spend more time attending to sick family members, which results in increased health risks and reduced income generation. The drought adaptation project is intended to identify and promote alternative livelihood options to unsustainable coping mechanisms and promote best practices especially for women and youth.

The EAC Climate Change Policy (2011) obliges partner states to do the following in recognition of the differentiated vulnerability, impacts, and roles of women, men, and youth in responding to climate change:

1) Integrate gender considerations in assessing vulnerability, impacts, and risks of climate change at local, national, and regional levels.
2) Promote involvement of women in climate change monitoring, adaptation, and decision-making processes.
3) Promote social protection programs for women and youth.

The risks and vulnerability to climate change and gender inequality are intricately linked. Therefore, gender needs to be mainstreamed in all development projects and programs to facilitate the identification of gender gaps. A gendered situational analysis on vulnerability of communities and sectors to climate change is important. It is evident that closing the gender gap in access to resources can improve incomes and productivity. The social norms that constrain women and youth access to agricultural resources can be eliminated to promote gender equality and economic development (FAO 2011).

5. SUGGESTIONS FOR SECTOR ADAPTATION OPTIONS

The LVB supports Africa's largest inland fishery and is of critical socioeconomic importance. About 30 million people in the LVB rely primarily on subsistence agricultural and livestock production for their livelihoods. Their economic activities include fishing, farming, livestock keeping, bee keeping, trading activities, quarrying, and mining. Hence, the perceptions and practices related to the exploitation of natural resources are closely intertwined with livelihoods and culture.

Agriculture contributes 40 percent of the region's GDP and provides a living for 80 percent of East Africans. Population pressure is a major driver of change in the Lake Victoria ecosystem, especially its increasing size, rapid growth rate, and increasing urbanization and immigration. In the upper reaches of many rivers, the main threats to wetlands are reclamation for agriculture, overgrazing, agricultural and industrial pollution, siltation, human settlement and encroachment, introduction of exotic species such as blue gum trees (*Eucalyptus* spp.), and overharvesting of water-dependent plants. The degree of threat varies from one county to another.

Poverty levels are high and agricultural production is low. In sum, the LVB is marked by negative trends for living conditions, the environment, and natural resources. Smallholder farmers in East Africa are highly vulnerable to the impacts of climate change and climate variability, largely attributable to their low adaptive capacity. The impacts of climate variability and change in East Africa in general and the LVB in particular is likely to be compounded by existing development challenges of high population growth rates, high and increasing poverty levels and low per capita incomes, high levels of inequality, and declining GDP growth rates. Climate change has the potential to undermine and even undo significant gains in social and economic development in East Africa.

Because not all communities are equally endowed with environmental and social assets, disaster vulnerability differs between regions, countries, and socioeconomic groups, the economic losses stemming from disasters can consume a significant proportion of their income and set their economic development back for several years. The indirect economic impacts of climate-related disasters are substantial for poverty alleviation and sustainable development.

In the light of climate change in the East African region, the following adaptation strategies could help reduce vulnerability in the region. These recommendations focus on establishing policies and investment strategies that address large-scale and long-term threats to commodity value chains, livelihoods, and agricultural institutions. It includes recommendations that facilitate local adaptation over shorter time periods, with an emphasis on improving the content and pathways for communicating information between researchers, scientists, and farmers.

Table 18: Suggestions for options

Option	Elements
General	a. Build the capacities of the National Meteorological Authorities (NMA)/ Departments of Meteorology (DOM); Climate Change Units (CCUs); and Ministries of Agriculture to improve the production, distribution, and use of climate information that responds to the needs of decision makers, as well as those of farmers and other stakeholders. b. Provide necessary technical and financial support to the NMA/DOM and CCU for the development of national climate datasets and information. c. Build capacities of regional institutions to develop and routinely use downscaled climate projections. d. Develop a platform/mechanisms for results (current trends and projections) to be shared at regional, national, district, and local levels. e. Restore wetlands, soils, and habitats as many agro-ecosystem services in LVB, such as the provision of clean water, creation of fertile soil, and maintenance of micro-climates/habitats, are deteriorating.
Assist regional governments to organize and develop high-level, multisectoral bodies to support CCUs to strengthen the climate change agendas and guide policy development	a. Create multisectoral coordinating committees, led by CCUs, to regularly meet and plan cross-sector coordination and strategic investment regarding long-term climate change impacts. b. Mainstream a climate change perspective into the programming of agricultural and natural resource management services.
Support and promote research and outreach at regional, district, and community levels	a. This set of recommendations refers to how knowledge and information related to climate change adaptation is generated and shared. b. Consistent with the framework, recommendations encourage the decentralization and democratization of innovation and planning, while also improving the exchange of information among all actors concerned with adaptation, and quickening the pace at which they learn from each other. c. Develop a wide range of technologies, practices, and interventions along commodity value chains: high-yielding and climate-appropriate crop varieties and livestock species, farm management strategies (focused on diversification and intensification of farming), and post-harvest storage strategies from which farmers can choose. d. Ideally, multi-stakeholder dialog and platforms, similar to the one recommended above, shape the evolution of the choices generated with and for farmers. Adaptive choices should meet the locally specific challenges of the following items: e. Climate change studies in relation to future agriculture production. International, regional research organizations, EAC, and universities (department of climate change within the region) develop scenarios of possible future climate conditions and the potential impacts crops and livestock.
Address gradual increase in temperature as the top priority given the certainty of the outcome and its likely impact on key crops and livestock	a. Invest in development of maize and bean varieties that tolerant rising temperatures (and continue to meet local preferences). b. Invest in shading and other temperature-reducing management techniques, a top priority for coffee and bananas.

Option	Elements
	c. Improve soil moisture management to offset expected increases in evapotranspiration.
Address changing rainfall as patterns and intensities affect soil moisture, crop growth at different stages, post-harvest storage conditions, and especially increases in "dry season" rainfall	a. More clearly define the challenges and needs in each of the five LVB countries based on local conditions to develop appropriate research agendas. b. Develop and promote pest- and disease-resistant varieties in all districts, with an emphasis on pests and diseases that thrive in moist environments. c. Promote improved soil management (moisture and fertility) techniques. d. Prevent disease and pests associated with increasing temperatures and variable rainfall by maintaining reserves of protected or treated seeds and plants that are disease- and pest-free at district research centers, which improves recovery after disease outbreaks and protects planting material for the next season. e. Develop management strategies that reduce pest and disease risk (i.e., improve storage facilities). f. Promote synergy between formal agricultural research with farmer-led innovation.
Strengthen the capacity of farmer groups to experiment with new ideas and to adapt them to local environmental and social conditions	a. Promote active participation and leadership by women and men, old and young, and poor and "better-off" to ensure the best mix of adaptive innovations. b. Pilot programs for farmer experimentation and innovation can be undertaken where local social capital is strong but overall vulnerability is high. These programs can provide lessons for setting up innovation systems elsewhere. c. Strengthen the capacity of farmer organizations to link laterally (among themselves) and vertically (with other research institutions at district and regional levels) to scale up the dissemination of successful innovations and adaptations.
Invest in Livelihood strengthening and diversification	These recommendations address the need to develop and diversify livelihood assets as a strategy for reducing household sensitivity to crop-related stresses. The goal is to build on existing livelihood-strengthening programs and improve the capacity of farmers to strengthen and diversify their livelihoods. a. Provide opportunities to spread financial risk in agriculture to allow for greater innovation and adaptation. This includes financial instruments, such as strengthening loan and insurance programs, and strengthening farmer organizations and their links to markets. b. Strengthen assets to encourage innovation, diversify livelihoods, and improve adaptive capacity. Assets are a key variable that distinguishes most vulnerable from least vulnerable households. Investing in asset growth for the most at risk will greatly reduce their vulnerability. Some of the most important assets are: • Financial assets. Expand savings and loan programs, micro-grants for tree planting, livestock purchasing, and land management programs. • Human capital. Expand training and technical backstopping to encourage local investments in agricultural processing and marketing, particularly in areas where human capital is weak and where off-farm opportunities are weak. • Social capital. Promote and strengthen community-based organizations—farmers' associations and self-help and watershed management groups—and contract farming with preferred consumers in areas where social capital may be significant, but where links to climate change–related issues are weak.

Option	Elements
Regional government ministries and institutions, nongovernmental organizations, community-based organizations, and the private sector, to invest in less climate-dependent livelihoods	Investments should target locations where agriculture-based livelihoods are under the most pressure from climate change and other environmental and social developments. Target areas should also consider, however, whether non-agricultural livelihoods are promising. Specific recommendations: ❖ Promote agricultural processing. ❖ Develop apprenticeship programs for youth. ❖ Support functional numeracy and literacy training along with basic business skills training where there are opportunities for commercial activities. ❖ Support programs that improve school assistance and retention rates, particularly for girls.
Improve preparedness for outbreaks of climate change–related disease and pest epidemics	a. Use conventional and modern molecular methods of improvement varieties for tolerance to abiotic (insect, diseases) stressors like heat, drought, flood, salinity. Early-maturing varieties are important to escape drought and outbreak of pests and diseases. b. Develop early warning systems for climatic hazards and pest outbreaks including wind breaking and appropriate drainage of areas prone to waterlogging is appropriate adaptation strategy. c. Promote knowledge of good agricultural practices, including integrated pest management tools and practices.

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APPENDIX

The parameter estimates and univariate model diagnostics for assessing how well the selected VARMAX(2,2,0) model fitted to the maize yield per hectare data for western and VARMAX(3,2,0) model fitted to the maize yield per hectare data for the Nyanza region of Kenya.

Table 19: Model parameter estimates for maize yield per hectare for the Nyanza and western regions of Kenya

Region	Parameter	Estimate	SE	t value	Pr > |t|	Variable
Nyanza	CONST1	-2.75895	4.28162	-0.64	0.5231	1
	XL0_1_1	0.45724	0.50836	0.9	0.3739	Annualrain(t)
	XL1_1_1	1.04859	0.71149	1.47	0.1486	Annualrain(t-1)
	XL2_1_1	-0.06095	0.93151	-0.07	0.9482	Annualrain(t-2)
	XL3_1_1	1.09136	0.94652	1.15	0.2559	Annualrain(t-3)
	XL4_1_1	1.36747	0.97494	1.4	0.1686	Annualrain(t-4)
	XL5_1_1	1.10512	0.84259	1.31	0.1973	Annualrain(t-5)
	XL6_1_1	-0.23094	0.65782	-0.35	0.7274	Annualrain(t-6)
	AR1_1_1	-0.29532	0.13422	-2.2	0.0338	yield(t-1)
	AR2_1_1	0.11413	0.12916	0.88	0.3823	yield(t-2)
	AR3_1_1	0.34744	0.13308	2.61	0.0128	yield(t-3)
	MA1_1_1	-0.89197	0.1281	-6.96	0.0001	e1(t-1)
	MA2_1_1	-1	0.10871	-9.2	0.0001	e1(t-2)
Western	CONST1	1.32876	1.0462	1.27	0.2116	1
	XL0_1_1	0.80037	0.43786	1.83	0.0752	Annualrain(t)
	XL1_1_1	-0.86702	0.74531	-1.16	0.2518	Annualrain(t-1)
	XL2_1_1	-1.08897	0.82306	-1.32	0.1935	Annualrain(t-2)
	XL3_1_1	0.61557	0.91074	0.68	0.5031	Annualrain(t-3)
	XL4_1_1	0.1792	0.86338	0.21	0.8367	Annualrain(t-4)
	XL5_1_1	-0.82255	0.6665	-1.23	0.2245	Annualrain(t-5)
	XL6_1_1	0.18185	0.5589	0.33	0.7466	Annualrain(t-6)
	AR1_1_1	1.31307	0.24726	5.31	0.0001	yield(t-1)
	AR2_1_1	-0.46875	0.24434	-1.92	0.0624	yield(t-2)
	MA1_1_1	1.26614	0.15115	8.38	0.0001	e1(t-1)
	MA2_1_1	-1	0.11477	-8.71	0.0001	e1(t-2)

Table 20: Portmanteau Test for Cross-Correlations of Residuals

The results show tests for white noise residuals based on the cross-correlations of the residuals. Insignificant test results show that we cannot reject the null hypothesis that the residuals are uncorrelated.

Region	Up To Lag	Degrees of Freedom	Chi-Square	Pr > ChiSq
Nyanza	6	1	4.19	0.0406
Nyanza	7	2	4.22	0.121
Nyanza	8	3	4.46	0.2156
Nyanza	9	4	4.87	0.3009
Nyanza	10	5	5.07	0.4076
Nyanza	11	6	5.07	0.5346
Nyanza	12	7	6.52	0.481
Western	5	1	2.17	0.1405
Western	6	2	3.82	0.148
Western	7	3	3.84	0.2789
Western	8	4	4.51	0.3419
Western	9	5	4.8	0.441
Western	10	6	5.46	0.4863
Western	11	7	7.78	0.3524
Western	12	8	8.02	0.4316

Table 21: Univariate model ANOVA diagnostics for maize yield per hectare

The results show that each model is significant

Variable	R-Square	Standard Deviation	F Value	Pr > F
Nyanza	0.7903	0.28294	8.16	<0.0001
Western	0.6052	0.23716	3.76	0.0024

Table 22: Univariate model white noise diagnostics for maize yield per hectare

The results test whether the residuals are correlated and heteroscedastic. The Durbin-Watson test statistics to test the null hypothesis that the residuals are uncorrelated. The Jarque-Bera normality test tests the null hypothesis that the residuals are normally distributed. The F statistics and their p-values for ARCH(1) disturbances test the null hypothesis that the residuals have equal covariances.

Variable	Durbin-Watson	Jarque-Bera normality test		ARCH(1) test	
		Chi-Square	Pr > ChiSq	F Value	Pr > F
Nyanza	1.818	0.23	0.8912	0.07	0.7928
Western	2.09441	2.15	0.3412	6.22	0.0174

Table 23: Univariate AR model diagnostics for maize yield per hectare

The F statistics and their p-values for AR(1), AR(1,2), AR(1,2,3), and AR(1,2,3,4) models of residuals test the null hypothesis that the residuals are uncorrelated.

Season	AR(1)		AR(1,2)		AR(1,2,3)		AR(1,2,34)	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Nyanza	0.18	0.6775	0.97	0.3875	0.64	0.5957	0.6	0.6646
Western	0.87	0.3563	0.12	0.8897	0.13	0.9445	0.44	0.7781

Table 24: Roots of AR and MA characteristic polynomials
The modulus of the roots of its AR polynomial should be less than 1 for a time series to be stationary.

	Roots	Index	Real part	Imaginary part	Modulus	Arctagent	Degree
Nyanza	AR	1	0.66417	0	0.6642	0	0
	AR	2	-0.47974	0.54127	0.7233	2.296	131.5516
	AR	3	-0.47974	-0.54127	0.7233	-2.296	-131.5516
	MA	1	-0.44599	0.89504	1	2.0331	116.4864
	MA	2	-0.44599	-0.89504	1	-2.0331	-116.4864
Western	AR	1	0.65654	0.19419	0.6847	0.2876	16.4769
	AR	2	0.65654	-0.19419	0.6847	-0.2876	-16.4769
	MA	1	0.63307	0.77409	1	0.8853	50.7229
	MA	2	0.63307	-0.77409	1	-0.8853	-50.7229

Table 25: Summary of observed and model

Region	Period	Scenario	Yield mean	Forecasts for Yield mean	Yield CV (%)	Forecasts for Yield CV (%)
Nyanza	1970-1990	MPI-26-2006-2100	2.02996	2.29241	31.3185	13.7795
Nyanza	1970-1990	MPI-45-2006-2100	2.02996	2.29241	31.3185	13.7795
Nyanza	1970-1990	MPI-85-2006-2100	2.02996	2.29241	31.3185	13.7795
Nyanza	1991-2014	MPI-26-2006-2100	2.08702	2.16752	25.1485	17.5642
Nyanza	1991-2014	MPI-45-2006-2100	2.08702	2.16752	25.1485	17.5642
Nyanza	1991-2014	MPI-85-2006-2100	2.08702	2.16752	25.1485	17.5642
Nyanza	2015-2030	MPI-26-2006-2100	.	2.81704	.	11.0415
Nyanza	2015-2030	MPI-45-2006-2100	.	2.65337	.	18.4933
Nyanza	2015-2030	MPI-85-2006-2100	.	2.11817	.	23.8605
Nyanza	2031-2050	MPI-26-2006-2100	.	2.21752	.	17.8075
Nyanza	2031-2050	MPI-45-2006-2100	.	2.58282	.	11.0851
Nyanza	2031-2050	MPI-85-2006-2100	.	2.14685	.	18.2603
Nyanza	2051-2070	MPI-26-2006-2100	.	2.32179	.	12.3055
Nyanza	2051-2070	MPI-45-2006-2100	.	2.44319	.	15.2948
Nyanza	2051-2070	MPI-85-2006-2100	.	2.48004	.	20.6446
Nyanza	2071-2100	MPI-26-2006-2100	.	2.40768	.	19.2398
Nyanza	2071-2100	MPI-45-2006-2100	.	2.43986	.	21.4081
Nyanza	2071-2100	MPI-85-2006-2100	.	2.88669	.	18.1894
Western	1970-1990	MPI-26-2006-2100	2.22583	2.24727	14.4665	6.5149
Western	1970-1990	MPI-45-2006-2100	2.22583	2.24727	14.4665	6.5149
Western	1970-1990	MPI-85-2006-2100	2.22583	2.24727	14.4665	6.5149
Western	1991-2014	MPI-26-2006-2100	2.21431	2.20428	21.4316	18.6534
Western	1991-2014	MPI-45-2006-2100	2.21431	2.20428	21.4316	18.6534
Western	1991-2014	MPI-85-2006-2100	2.21431	2.20428	21.4316	18.6534
Western	2015-2030	MPI-26-2006-2100	.	1.59872	.	15.2222

Region	Period	Scenario	Yield mean	Forecasts for Yield mean	Yield CV (%)	Forecasts for Yield CV (%)
Western	2015-2030	MPI-45-2006-2100	.	1.62317	.	19.0018
Western	2015-2030	MPI-85-2006-2100	.	2.31246	.	26.1123
Western	2031-2050	MPI-26-2006-2100	.	2.16529	.	20.2624
Western	2031-2050	MPI-45-2006-2100	.	2.10355	.	14.4743
Western	2031-2050	MPI-85-2006-2100	.	2.62227	.	19.619
Western	2051-2070	MPI-26-2006-2100	.	2.15064	.	23.5329
Western	2051-2070	MPI-45-2006-2100	.	2.16452	.	25.5874
Western	2051-2070	MPI-85-2006-2100	.	2.08269	.	25.6146
Western	2071-2100	MPI-26-2006-2100	.	2.36042	.	26.4661
Western	2071-2100	MPI-45-2006-2100	.	1.94659	.	32.434
Western	2071-2100	MPI-85-2006-2100	.	1.44113	.	45.9055

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