Crops & Climate Change: Maize

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Summary

Climate change is projected to adversely affect agriculture in most developing countries. In particular, researchers expect that agriculture in Sub-Saharan Africa (SSA) will experience major impacts from climate change, leaving the already food-insecure region subject to large contractions of agricultural incomes and food availability. [1,2] As part of the Crops & Climate Change series, this brief is presented in three parts:

- Pillar 1: An evaluation of the importance of maize in SSA, based on production, net exports, and caloric need
- Pillar 2: A novel analysis of historical and projected climate conditions in maize-growing regions, followed by a summary of the agronomic and physiological vulnerability of maize crops
- Pillar 3: A summary of current resources dedicated to maize, based on research and development investments and National Adaptation Programmes of Action

This three-pillared approach will identify gaps in resources dedicated to maize productivity in SSA. The approach will consider productivity in light of the crop's resilience to projected changes in climate and its importance in the region's food security.

Overall, this analysis indicates that the importance of maize as a food crop remains high throughout SSA. Significant portions of maize-growing SSA will face climate conditions outside the range of country- and continent-level historical precedent.[3] Rising temperatures and changes in precipitation are predicted, and reductions in maize yield and production will likely follow. Resources intended to aid adaptation to climate change flow primarily from public sector research and development efforts.[4] Country-level adaptation strategies are often hampered by lack of funding and insufficient institutional capacity.[5] Strategies for adaptation include improved agricultural practices and technology as well as infrastructure and program investments to absorb the impacts of climate change.

Pillar 1: The Importance of Maize in SSA

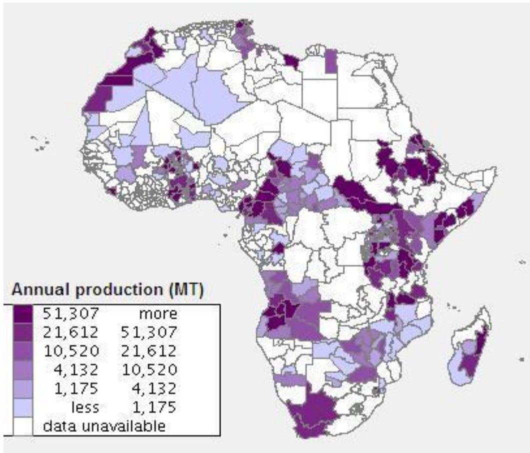
Maize is one of the most important food crops in Sub-Saharan Africa (SSA). It provides a higher proportion of calories to SSA than does any other crop; nearly 40% of the SSA population relies on maize in their daily diet.[6] Demand for maize is increasing at a rapid rate in SSA as well as globally. By 2020, maize demand in SSA is projected at 52 million tons, nearly double 1995 levels.

Maize Production in Sub-Saharan Africa

Maize is grown throughout SSA, with the highest production levels in southern Africa and in a belt running approximately from the Somalian coast in the east to Mali and Mauritania in the west (Figure 1). In 2008, SSA produced nearly 50 million metric tonnes of maize, at an average yield of 1.6 MT per hectare. Major producers are found in the eastern and southern portion of the continent. South Africa is the leader in both production and yield; in 2008 South African farmers produced nearly 12 million metric tonnes at an average yield of 4.14 MT/hectare.[7] While high-yielding temperate maize varieties are the most common globally and in developed regions, Sub-Saharan Africa produces almost entirely tropical maize: 1.7 million hectares in the tropical highlands, 8 million hectares in the subtropics and mid-altitude tropical zones, and 12.3 million hectares in the tropical lowlands.[8]

In part because of the varietal differences and in part because of agro-ecological constraints, maize yield levels in SSA are significantly lower than yield levels worldwide.[9]

Figure 1. Maize production in Africa by administrative district



Source: FAO Agro-Maps

The predominant farming systems for maize are (1) cereal-root crop mixed (covering 13% of SSA and contributing 15% of SSA agricultural production) and (2) maize mixed (covering 10% of SSA and contributing 16% of SSA agricultural production).[10] The maize mixed system supports livestock keepers as well as croppers, and it is the most important maize production system in East and Southern Africa. It is characterized by a dry- to moist-subhumid climate, large highland areas and an average farm size of two hectares. The cereal-root crop mixed system has a larger average farm size, lower altitude, and higher temperatures than the maize mixed system. Root crops are more significant in this region than maize. Both production systems are almost entirely rain-fed.[11]

Maize Consumption in Sub-Saharan Africa

Table 1. Dependency on Maize for Caloric Intake

Level of Dependency	Countries	Population
Very Highly Dependent >800 kcal/person/day	Lesotho, Malawi, Zambia, Zimbabwe	42,357,000 (5.3% of SSA)
Highly Dependent 500-799 kcal/person/day	Kenya, Tanzania, Swaziland	73,588,950 (9.2%)
Moderately Dependent 300-499 kcal/person/day	Angola, Benin, Botswana, Burkina Faso, Cameroon, Cape Verde, Ethiopia, Ghana, Mozambique, Namibia, Togo	194,398,945 (24.4%)
Less Dependent <300 kcal/person/day	Remaining SSA countries	427,609,618 (53.7%)

Source: FAOSTAT; CIA World Factbook; Authors' calculations

Nearly 15% of SSA is highly dependent on maize, with a per capita caloric intake from maize at or above 500 kcal/day, or between 25-50% of the recommended daily caloric intake for adults.[12,13] The average per capita protein consumption from maize in SSA is 8 grams per day, but where maize is the main source of calories, maize provides approximately half the 46-56 grams of protein recommended per day.[14]

Maize-producing countries in the cool tropics, such as Kenya, Tanzania, Zambia, Zimbabwe, and Malawi, obtain a greater portion of calories and protein from maize than do countries in the rest of SSA (Table 1). For detailed production information by country, see Appendix I.

Pillar 2: Vulnerability Analysis of Maize-Growing Regions in SSA

Climate change will affect agriculture by altering yields and changing the area where crops can grow.[15] The combination of climate factors and plant physiological responses to it will affect maize cultivation in complex ways, both positive and negative.[16] The first portion of this analysis will use historical data and climate model projections to provide novel regional estimates of climate conditions, variability, and projected climate change in maize-growing SSA.[†] The second portion of the analysis will review the literature to provide an overview of maize's agronomic and physiological vulnerability to climate change.

Climate Analysis: Background

Temperature shifts are a well-understood response to rising greenhouse gas concentrations and associated radiation and circulation changes (IPCC, 2007). Under an emissions scenario consistent with current development trends, IPCC-coordinated climate model results project a high likelihood of warming across SSA during the twenty-first century. Annual mean surface temperature is expected to increase approximately 0.5–1.0°C by 2029 and 3–4°C by 2100. Elevated areas in southern Africa may see increases of up to 7°C by 2100.[17,18,19]

Significant changes with respect to growing season temperatures are likely; nearly all maize-growing regions in SSA are projected to move quickly out of the range of historical experience. By 2025, the distribution of growing season temperatures in maize-growing regions will overlap with the historically observed temperature distribution by 58% on average. By 2050, the overlap is projected to have dropped to 14%, resulting in 20 countries experiencing temperatures outside the range represented in the historical climate record. By 2075, the average overlap for maize-growing regions in SSA is projected to drop to 3%, wherein the coldest summers of the future will be reminiscent of the hottest summers of the 20th century.[20] The overlap in coastal areas shrinks more quickly than in inland areas, largely because coastal areas have experienced less historical variability.

Researchers predict that in 11 SSA countries, the overlap of current growing season temperature and projected future conditions will be less than 20% by 2050. In other words, by 2050 four out of five years will have an average growing season temperature above the warmest observed during the twentieth century. Projections vary for the rest of SSA, with only Tanzania, Malawi, Benin, Ethiopia, and Lesotho projected to experience temperature overlap of 80%.[21] *Figure 5* illustrates this analysis showing two sets of hypothetical temperature distributions. The left panel shows distributions with some degree of overlap; in the right panel, however, the distributions do not overlap. Regions characterized by a change such as that shown in the right panel are said to encounter a "novel" climate beyond the observed twentieth century climate. Some countries will likely approach climate conditions that are novel at the continent level, especially those in the hotter Sahelian region. Senegal, Mali, Chad, Niger, and Burkina Faso are projected to achieve climate conditions with little to no current representation in the world.[22]

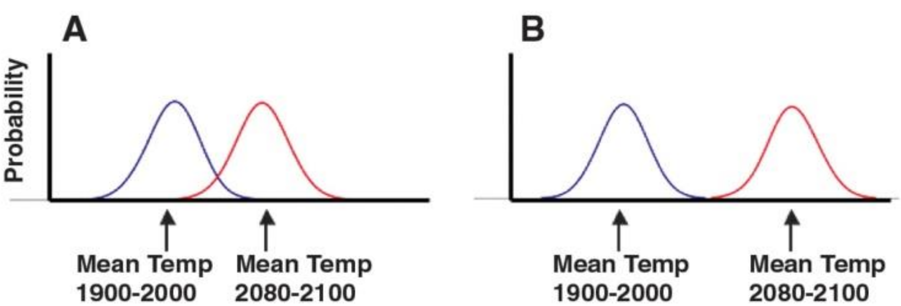


Figure 5. Hypothetical distributions of growing season average temperature for the 20th century (blue) and late 21st century (red). A: some overlap; future mean growing season average temperature is equal to hottest 20th century mean. B: no overlap; distribution of late 21st century growing season temperature exceeds historical distribution completely. Source: Battisti & Nayor, 2009

Projected changes in precipitation are generally less robust than their temperature counterparts.[23] The factors affecting precipitation are considerably more complicated than those affecting temperature, and involve small-scale phenomena such as thunderstorms. Estimates vary widely by model, region, and emissions scenario. This is a particular issue in arid- or semi-arid

† This analysis is the product of a Program on Climate Change capstone project by Brian Smoliak, PhD Candidate, Department of Atmospheric Sciences, College of the Environment, University of Washington. For permission to disseminate results, please contact the authors.

regions where small absolute changes can be of a high relative magnitude and importance.

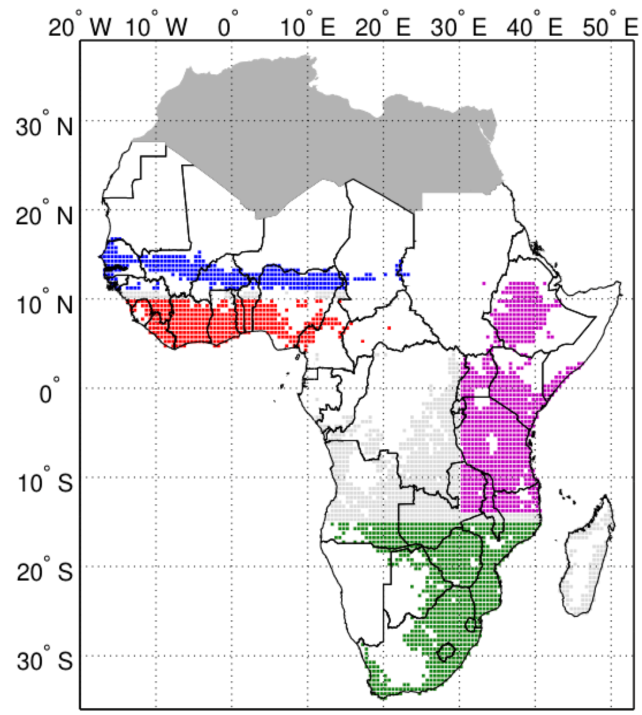
Despite pronounced uncertainty in some regions, IPCC has characterized several robust changes related to precipitation.[24] The IPCC considers four specific changes in rainfall patterns to be likely. Firstly, mean annual rainfall will increase in tropical and eastern Africa. Secondly, winter rainfall will decrease in southern Africa. Thirdly, summer rainfall will increase in equatorial regions (north of 10ºS and east of 20ºE). And finally, summer rainfall will decrease in regions south of 10ºS. The onset and length of the rainy season are not projected to change in response to anthropogenic global warming.[25]

Notwithstanding agreement on the direction of precipitation changes for the aforementioned regions and seasons, some models project a drying of the western Sahel, while others project increased precipitation more consistent with the strong multi-decadal variability historically observed in that region.[26] Average overlap between distributions of historical and future precipitation is projected to fall to 86% by 2025, 84% by 2050, and 82% by 2075. These changes are for the entire western Sahel, not specific to maize-growing portions of that region, which is presented more specifically in the following section. Across Africa changes in precipitation will occur in both directions; some areas will become wetter and some will become drier. These projections are consistent with previous, independent assessments of African climate change and the robust changes in precipitation that IPCC projects.[27] Future regional assessments will be necessary to isolate changes in the meteorological phenomena that contribute to precipitation and its variability over SSA, for example, the timing of afternoon thunderstorms or the position of the Intertropical Convergence Zone, a region of persistent intense thunderstorm activity.

The most sophisticated global climate models can produce robust projections with a resolution of 250 by 250 kilometers.[28,29] At this level of detail, only about 500 grid cells, each approximately the size of Sierra Leone, represent all of SSA. While this scale is sufficient to describe continental and regional changes, it is difficult to describe changes at the country level or below. Novel statistical techniques, broadly referred to as downscaling, can produce higher resolution climate projections.[30,31,32]

For this analysis, researchers used global crop distribution data and twentieth century climate data to define four representative categories of growing season climates in SSA: Sahel, Coastal West Africa, Southern Africa, and East Africa.[33,34] *Figure 2* illustrates the geographic domains of each region. The regions have unique annual variations of growing season temperature and precipitation, which strongly influence agriculture through their effect on plant biology and environmental conditions. The representative regions have experienced varying degrees of prolonged climate change over the twentieth century apart from year-to-year variability. Considering future change in the context of this historical variability may yield a comprehensive interpretation of climate change.

Figure 2. Maize growing regions in SSA, including: Sahel (blue), Coastal West Africa (red), Southern Africa (green), East Africa (purple), and regions not included in the regional analysis (grey)



Source: Crop distribution data from Leff et al., 2004

Data

The historical temperature and precipitation data for this analysis come from the University of East Anglia (UEA), Climate Research Unit (CRU) time-series (TS) 3.0 dataset. The CRU TS 3.0 dataset incorporates land-based daily temperature and precipitation observations for the period 1901 to 2006, grids them to a uniform 0.5º latitude by 0.5º longitude grid (approximately 50 by 50 kilometers across most of SSA) at a monthly-mean resolution (i.e. one value of temperature or precipitation per month for each grid point). This spatial resolution is 100 times greater than previously available 5º latitude by 5º longitude datasets. It incorporates monthly-mean observations of six climate variables including temperature and precipitation for stations around the world. State-of-the-art methodology and output to a regular 0.5º latitude by 0.5º longitude grid ensure the quality of the observations. Only observations for sub-Saharan Africa are used for this analysis. Although there is a paucity of data over SSA compared to developed countries, nearly complete spatial coverage is available.[35] Furthermore, strong statistics may be obtained for the complete twentieth century and the most recent two or three decades.

Methods

The future projections are based on model output from 23 models used for the IPCC AR4. These models originate from independent modeling centers around the world. Each is a unique representation of Earth's climate system, including the land surface, the atmosphere, the ocean, and the cryosphere, Earth's frozen water. While all of the models share the same governing equations, they differ in their treatment of phenomena that cannot be fully resolved (i.e., operate on spatial scales smaller than the models grid spacing), such as thunderstorms, small-scale turbulence, and atmospheric aerosols. Averaging the results of these models, some having more than one run (i.e., a single model simulation of the future climate), is a best practice of current studies on future climate. This "ensemble mean" has many statistical degrees of freedom, and expresses the consensus between the various models.

To define the four maize-growing regions, researchers use an objective assessment of SSA areas where maize is grown and a subjective grouping of grid cells into four macro-regions with similar growing season climates. Growing season is defined for each region based on digitization and geo-referencing of observed crop planting and harvesting dates.[36] Historical distributions are defined by an area-average of grid points within maize-growing regions with a 1976–2006 mean and variability based on the entire twentieth-century record (see *Table 3*). Mean and standard deviation are calculated only for growing season months and only for those grid cells in which maize is grown. To provide relevance for current agronomic conditions, this analysis considers average conditions over the last 30 years, but variability over the entire twentieth century.

The analysis of projected climate change uses a methodology similar to previous studies,[37] quantifying the percentage of overlap between various projected climate variable distributions and historical observations. Our analysis is performed for growing season average temperature and extended to growing season total precipitation. Projected future distributions of temperature and precipitation are presented at three years: 2020, 2050, and 2090, corresponding to near, intermediate, and long time horizons. The distributions are defined by two averages: the same area-average as in the historical distribution and an ensemble average of output from 23 climate models included in the IPCC AR4, each having one or more simulations totaling over 50 realizations of future climate.

The mean future distributions are determined by adding a shift to the 1976–2006 mean calculated from historical observations. These shifts are calculated as the difference between two 20-year averages: 1) means centered at 2020, 2050, or 2090 in simulations driven by emissions consistent with current development trends (SRES A1B) and 2) a mean centered at 1990 in each model's Climate of the 20th Century simulation (20C3M). The historical distribution of variance constrains the corresponding variance of future distributions, based on the assumption that variability has not changed significantly over the 20th century and the fact that climate models do a poor job of representing historical variability. In other words, while climate models can reproduce the climatological mean of temperature and precipitation, they are less able to depict the amplitude of their historical variability. The analysis is based on growing seasons as defined in *Table 3*, and assumes no shift in growing season or changes in farming strategies (such as double cropping or altering spatial distributions of crop planting).

Results

<u>Current and Historical Climate Conditions of Rice Growing Regions</u>

Table 3 presents area-averaged, growing season mean and standard deviation for temperature and precipitation over the four SSA sub-regions shown in Fig. 2. The nearby regions of Sahel and Coastal West Africa provide an example of strong contrasts. The Sahel is characterized by a comparatively hot and dry growing season, unsurprising given its proximity to the Sahara desert. Coastal West Africa's mean climate is strongly influenced by the North Atlantic Ocean and the steady march of seasonal wind patterns that bring moist maritime air ashore. Of the four regions considered here, Coastal West Africa is the wettest in recent history.

Southern Africa and East Africa are both cooler and wetter than the Sahel. While both of the former have approximately the same growing season mean temperature, East Africa is slightly drier, due in part to its higher elevation and subtropical location.

Whereas mean temperature gives a static picture of the growing season climate of these maize growing regions, standard deviation provides a depiction of how much temperature departs from the mean on a year-to-year basis. For temperature, the Sahel stands out above the three other regions with over 0.4ºC deviation from the mean on average. For precipitation, the Sahel and Southern Africa are set apart from the other regions with 1.55 and 1.45cm deviation from the mean on average, respectively.

Table 3. Growing season mean (μ; ºC, cm) and standard deviation (σ; ºC, cm) for temperature and precipitation over four maize growing regions in SSA (For relevance and stable statistics, means based on recent period, 1976-2006; standard deviation based on entire period of record, 1901-2006)

Region	Growing	μ(T)	σ(T)	μ(P)	σ(P)
Sahel	May - October	29.7	0.42	51.3	1.55
Coastal W. Africa	May - November	25.9	0.32	95.4	0.89
E. Africa	March - July	22.3	0.30	44.3	1.16
Srn. Africa	November - May	23.3	0.32	57.5	1.45

Source: University of East Anglia CRU TS 3.0 dataset

Figure 3 presents four time series of growing season average temperature anomalies relative to temperatures observed in the recent period 1976 to 2006. Figure 4 is identical to Fig. 3, but shows growing season total precipitation. Each time series corresponds to one of the four aforementioned regions, and illustrates the distinct character of temperature and precipitation variations during the twentieth century.

Coastal West Africa is also characterized by multi-decadal variability in temperature, but less so in comparison to the Sahel. The warming over Coastal West Africa is slightly less than half of what was observed in the Sahel, consistent with the former's proximity to the moderating influence of the North Atlantic Ocean.

Growing season average temperature over East Africa was relatively flat for the first half of the twentieth century, after which a positive trend larger than the year-to-year variability emerged. Conversely, Southern Africa saw a steadily-increasing positive trend in temperature throughout the century.

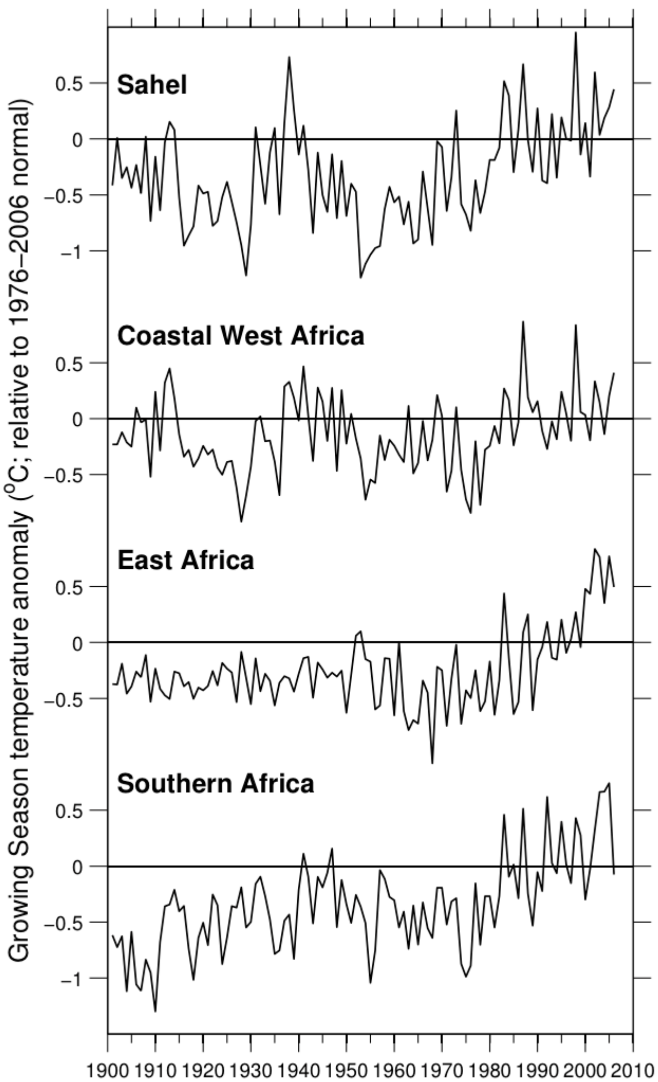
Precipitation

Except for the Sahel, long-term precipitation trends were small over Africa during the 20th century. Notwithstanding this fact, short-term (1-5 years) trends are evident within each time series in Fig. 4. This so-called interannual variability is a characteristic quality of African climate variability and likely dominates farmers' experience of year-to-year changes in growing season precipitation, particularly in regions with large precipitation variability.

For example, the time series of Southern Africa precipitation shows swings of up to 60% of the climatological mean growing season total precipitation over the course of 10 years and short-term jumps of 30% or more. A similar story is apparent in the time series of East Africa and Coastal West Africa precipitation, albeit with less dramatic shifts in magnitude.

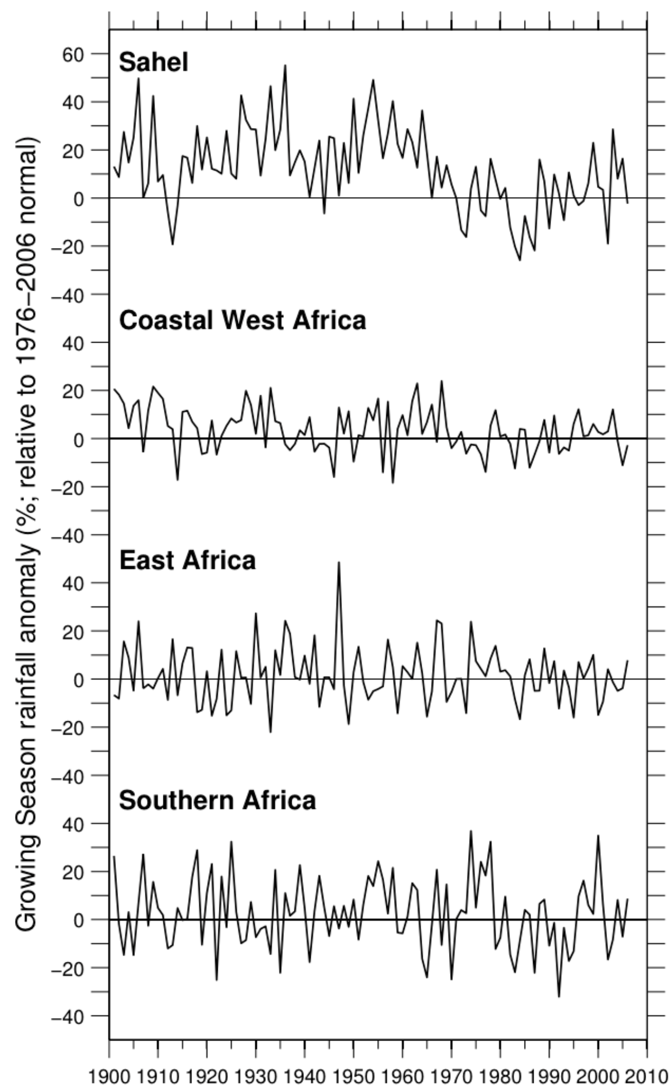
The exception of the Sahel for precipitation is related to multi-decadal variability. Over the twentieth century, the Sahel experienced a drying. The mostly-positive values in the Fig. 4 time series prior to 1970 indicates that the early to mid-twentieth century was much wetter than current growing seasons over the region. The region fell into a drought in the early 1970s, from which it has only recovered slightly since. Superimposed on top of this multi-decadal variability are pronounced year-to-year changes in precipitation, which may amplify or lessen the intensity of moisture-poor or moisture-rich decades. Short-term trends are also evident. For example, the increase in precipitation over the late twentieth century brought some relief to the 1970s drought.

Figure 3: Growing season average temperature anomalies relative to recently (1976-2006) observed temperatures. Four maize-growing regions shown, corresponding to Figure 2 and Table 3.



Source: UEA CRU TS 3.0

Figure 4: Growing season total rainfall anomalies expressed as a percentage relative to recently observed precipitation. Four maize-growing regions shown, as in Figure 3.



Source: UEA CRU TS 3.0

Projected 21st Century Climate Change in Maize Growing Regions

Temperature shifts are robust among the 23 models included in our analysis. Figure 6 shows historical distributions of growing season average temperature for the four regions and three future distributions corresponding to climate at 2020, 2050, and 2090. The magnitudes of the shifts themselves are similar, but the percentage of overlap varies spatially according to the degree of natural variability observed across each area.

For example, over the Sahel where large temperature variability is observed, the percentage of overlap is larger than the others at 2020 and 2050. In other words, an equivalent shift in the mean climate at a location with low variability (e.g., East Africa) will mean less overlap than for one with high variability (e.g., the Sahel). Notwithstanding this nuance, by 2090, each of the four regions is projected to move into a completely novel warmed climate, distinct from the observed twentieth-century climate there.

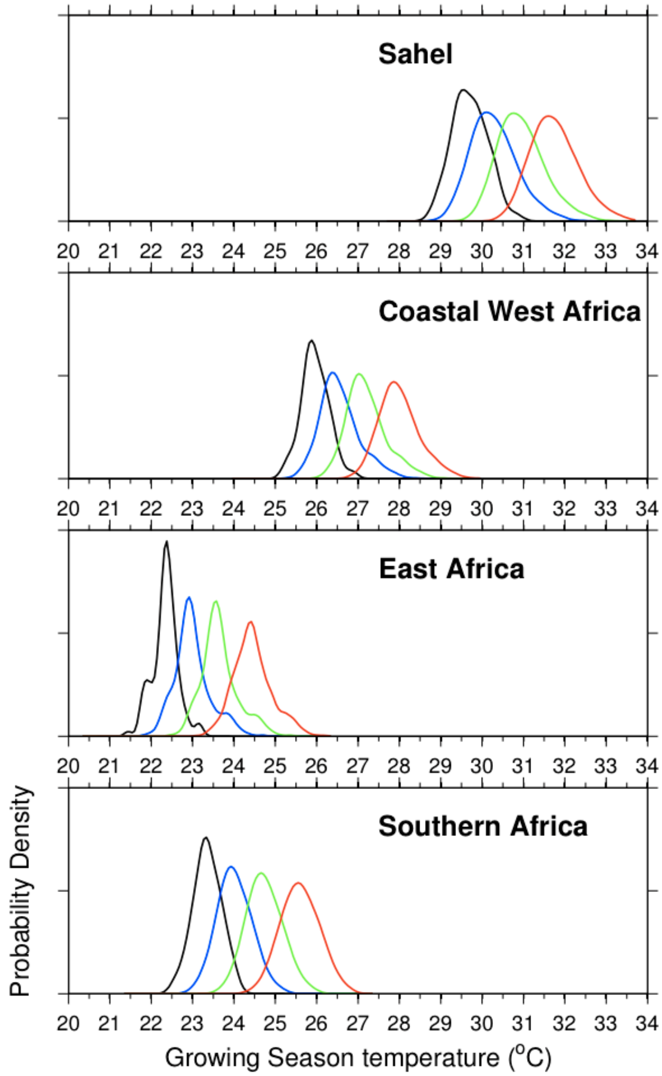
The shifts are less pronounced for precipitation than for temperature, reflecting a larger degree of agreement in the size of the shift amongst the models in time and space (Figure 7; Table 3). In other words, the models disagree over how large and of what sign precipitation changes will be across Africa (IPCC AR4, Figure SPM.7; Christensen et al. 2007). Thus, the distributions of precipitation shift only slightly and remain the same over the course of the twenty-first century.

Table 3: Percentage of climate overlap between recent (1976-2006) observations and future projections based on a business-as-usual development scenario used by IPCC climate models. Percentages indicated for temperature (T) and precipitation (P) at 2020, 2050, and 2090.

Region	**Variable**	**2020**	**2050**	**2090**
Sahel	T	66%	23%	0%
	P	90%	90%	91%
Coastal W. Africa	T	56%	7%	0%
	P	91%	91%	92%
E. Africa	T	43%	3%	0%
	P	84%	82%	85%
Srn. Africa	T	47%	4%	0%
	P	91%	92%	92%

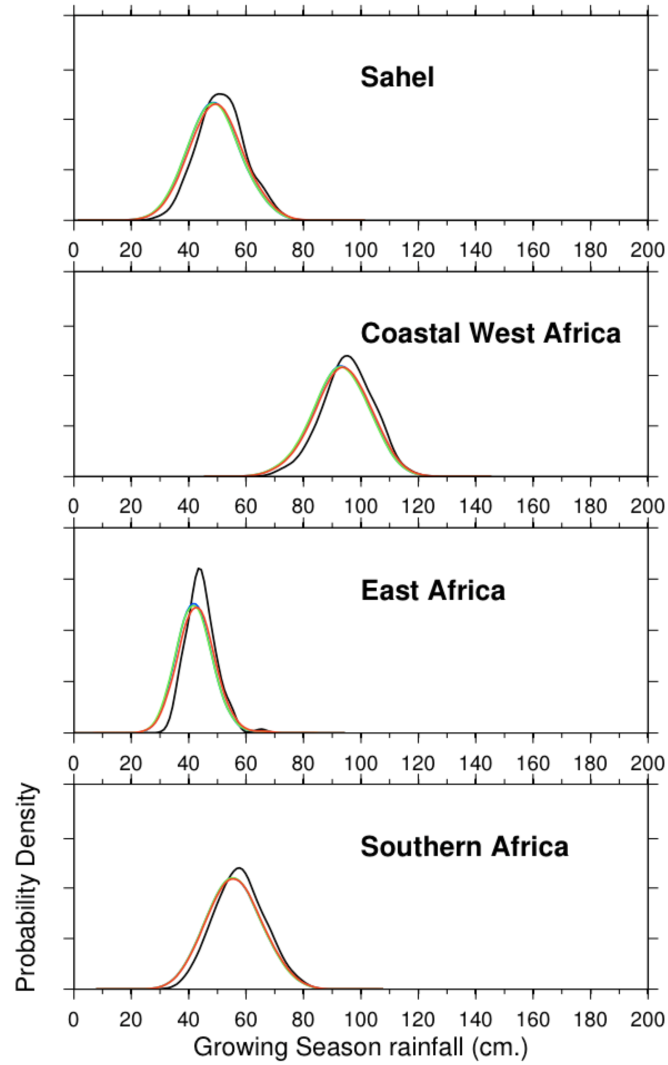
Source: UEA CRU TS 3.0 (historical data), Coupled Model Intercomparison Project database (future projections).

Figure 6. Shifts in average growing season temperature over four maize-growing regions in SSA. Distributions are shown for 1976-2006 (black), 2020 (blue), 2050 (green), and 2090 (red).



Source: UEA CRU TS 3.0 (historical data), Coupled Model Intercomparison Project database (future projections).

Figure 7. Shifts in total growing season precipitation over four maize-growing regions in SSA. Distributions are shown for 1976-2006 (black), 2020 (blue), 2050 (green), and 2090 (red).



Source: UEA CRU TS 3.0 (historical data), Coupled Model Intercomparison Project database (future projections).

Discussion

The results presented are consistent with previous studies, which find significant shifts in temperature and uncertain changes in precipitation.[38] The uncertainty of precipitation changes is not necessarily a barrier to action or source of significant doubt, due to its well-understood source. As previously noted, precipitation trends were small over the twentieth century and set amongst large year-to-year variability. This suggests that farmers in SSA have a strong experience set related to precipitation variability from which to draw. They may already have adaptation methods in place to mitigate the impact of a short-term drought or flood. On the other hand, persistent temperature increases constantly change the baseline from which maize farmers in SSA have to judge the present conditions. Furthermore, in some regions, including Southern Africa and East Africa, temperature is projected to increase outside of historically observed bounds by 2050, a not-too-distant time horizon. Coupled with even a slight decrease in precipitation, current varieties of maize would be extremely vulnerable in these regions.

An increase in temperature over each region suggests that the growing season may lengthen. However, this does not translate into more suitable conditions, given the associated slight decrease in precipitation. The growing season may become split in some areas, with a period at the peak of summer where temperature rises above the ideal conditions for maize, or when longer droughts reduce yield. Robust estimates of future yields will necessitate strong projections of growing season length, timing of precipitation and temperature relative to critical plant development stages, and climate-change-related shifts in secondary factors like pests, crop disease, and land use.

Future improvements in the models' ability to project the physical and dynamical factors that contribute to precipitation will likely increase confidence in future changes and allow a better characterization of shifts over these representative regions. Another way to increase confidence in precipitation projections would be to weight the results according to how well the model reproduces current and historical climate variability. Thus, models performing poorly would essentially be thrown out in favor of higher performers. Nonetheless, such an endeavor leads to additional assumptions regarding proper metrics, which themselves must be justified.

Agronomic and Physiological Vulnerability

Temperature and Precipitation Requirements

In most models, temperature changes have a stronger overall impact on maize production than do precipitation changes, but this is due in part to a lack of consensus about the magnitude and direction of changes in precipitation. Most SSA maize is rainfed, leaving it vulnerable to both water and temperature stresses.[39]

Plant-level productivity impacts are not only the result of single climate factors, but also of the interactions between those factors. Temperature, precipitation, CO2 levels, radiation, and changes in weed or pest populations can all work singly or in tandem to affect the environment and physiological state of the maize plant.

Climate change effects can be more or less pronounced across different varietals. There are multiple improved and landrace varieties planted throughout SSA, with varying levels of tolerance to climate-related stressors.[40,41,42] The variability in maize varieties makes it difficult to determine definitive thresholds for maize suitability. Susceptibility to the effects discussed in the following section will therefore vary to some extent by cultivar, but the basic mechanisms are generally applicable.[43]

Changes in plant physiology

Reduction of leaf canopy

Establishing a leaf canopy reduces evaporation significantly, but maize seedlings under drought and temperature stress are likely to have a longer lag time between seeding and leaf growth, increasing the period of vulnerability to high rates of evaporation. Maize varieties with rapidly-developing large leaf areas are less vulnerable to evaporation, but increased leaf production can reduce harvest index and overall yield.[44]

Changes in water use efficiency

Transpiration efficiency (TE) is the ratio of water assimilated to water transpired (lost from foliage). Higher TE translates to increased water use efficiency (WUE). TE decreases in drier air. Decreases in precipitation may therefore reduce maize WUE. Water stress can also reduce TE by inducing closure of the stomata, but the mechanism is not well understood. TE increases as the proportion of diffuse radiation (relative to direct radiation) increases; drying- and wind-related increases in atmospheric dust could potentially increase TE in maize and other plants.[45]

Timing of flowering

Timing of flowering has an important effect on yield and harvest index in maize and other plants. Plants that flower late may have used too large a portion of groundwater in the vegetative stage, leaving them more vulnerable to temperature or water stresses during post-flowering photosynthesis and grain filling.[46] High temperatures usually result in earlier flowering, but increased seasonal variability may make it more difficult for farmers to select the most appropriate cultivars. An early-flowering variety may do well in one season, while a late-flowering variety may be best adapted in the next.

<u>Changes in Agricultural Conditions</u>

Increased soil water evaporation

The majority of crop water loss is caused by evaporation, particularly in winter-rainfall regions. High temperatures—such as those projected throughout SSA—increase evaporation rates, reducing soil moisture levels and increasing crop water stress.[47,48]

Decreased fallow efficiency

Efficient fallow periods allow water to accumulate deep in the soil. Maize and other crops access this deep water in the flowering and grain-filling periods; an efficient fallow ensures adequate water access during those crucial periods. Climate change can reduce fallow efficiency in four ways: (1) higher temperatures contribute to increased soil water evaporation; (2) decreases in precipitation can decrease low-profile water storage; (3) extreme precipitation events may inundate the soil beyond its water-holding capacity, resulting in water and nutrient loss through deep drainage; and (4) increased CO_2 can contribute to deep-root weed growth, which leaches water from the soil.[49]

Changes in timing of water stress

Water deficits during floral development can reduce floral fertility and prematurely abort grain filling, leading to severe—sometimes complete—loss of yield in maize and other crops. Water stresses during grain filling can result in increased vegetative growth but reduced grain biomass and lowered harvest index. Yield losses can occur by these pathways even in the presence of adequate rainfall throughout the rest of the season.[50] Increases in climate variability may increase susceptibility to these timing-based losses.

Increased weed and pest stress

Maize is a C4 crop and most maize weeds are C3. C3 plants such as striga outperform C4 plants at higher temperatures, and their TE becomes more efficient in the presence of elevated C02. Rising CO2 levels also reduce the advantage of C4 plants in nitrogen-poor soil.[51]

Damage from insect pests may increase as well, both pre- and post-harvest. Higher temperatures may expand the range of several pests. They also increase the insect population by shortening the time span between insect generations and reducing the number of insects killed during the colder season.[52,53]

<u>Overall Impact of Climate Change on Maize Yields</u>

Jones and Thornton (2003) project yield decreases for most maize production environments, with the exception of: mesic subtropical cold winter, wet temperate cold, highland subtropical (mesic and wet), highland tropical (mesic and wet), mid-altitude subtropical (dry). Dry highland tropical and subtropical will be only slightly affected, but other dry tropical environments see substantial decreases. There are consistent decreases projected for the tropical lowlands, the dominant production environment for maize in the developing world.

In a meta-analysis of 16 climate change models by country to 2050, the mean estimate for maize production loss in SSA is 22%. This compares to average projected yield losses of 8-17% for other staple crops (sorghum, millet, groundnut, and cassava). Countries with the highest average yields have the largest projected losses, suggesting that well-fertilized modern seed varieties are more susceptible to heat-related losses.[54] Nelson et al (2009) project a 7-10% decrease in maize production in SSA, depending on the forecasting scenario used.

Reliable crop-growing days will be reduced in some areas. Transitional zones (areas in which reliable crop growing days fall below 90 by 2050) are identified mainly in rain-fed mixed crop-livestock systems. These zones are found in a band across West Africa between latitudes 10-12º N, mid-altitude zones in eastern Africa, parts of coastal eastern and southeastern Africa, and some mid-altitude areas running through central Tanzania, Zambia, Zimbabwe and South Africa.[55]

Case Studies

There are a number of small-scale and country-level studies of maize productivity under various climate change scenarios. These studies may provide a more detailed insight into possible interactions between maize and climate change, though their applicability on a broad scale is undetermined.

Chipanshi (2003) modeled climate changes based on data from two sites in arid, pastoral/agro-pastoral, food-poor Botswana, assuming doubling of CO_2. Botswana can be considered a marginal producer; it imports 70-96% of its cereals and its yields are among the lowest in SSA. Nearly all crops are rain-fed and cultivated with traditional technologies. Current yields are significantly below optimal levels and under simulated climate change, yield declines by 36%. Growing season is reduced from three to eight days, with particular hardships in the sand veldt (desert) region. Yield decreases in this model are due to higher temperatures.

Mati (2000) projects changes in maize yield in Kenya. The total yield is not predicted to change significantly by the year 2030, but distribution within country is likely to shift. This model projects no change in overall rainfall; increases in short-rain seasons will be offset by decreases in long-rain seasons. Yields decrease in higher, wetter areas and increase in lower, drier areas. Results indicate that planting date will have a significant effect in that earlier planting will increase yields.

Adejuwon (2005) used climate data for maize from 1983 to 1999 to analyze sensitivity to climate variability in the Nigerian Arid Zone.[56] The authors concluded that in the absence of irrigation, low rainfall makes crop yield more sensitive to variability.

Thornton et al (2009) project a decrease of up to 15% in potential crop production in eastern Africa by 2050. The study uses climate data to compare current and projected areas that could feasibly grow maize; the authors do not map actual current maize production.

Walker & Schulze (2008) model changes in maize productivity in South Africa. The authors project increased variability of crop yields, along with an overall reduction in productivity. These changes will have especially negative effects in the drier western regions of South Africa.

Overall, case studies suggest a trend towards decreases in maize production. This trend is consistent with projections based on large-scale climate models.

Pillar 3: Current Resources Dedicated to Maize in SSA

Climate change impacts will be determined not only by the susceptibility of crops to changing conditions, but also by the ability of people and institutions to adapt to those changes. Maize crop responses in a given area can fall into any of three categories: (1) the crop benefits from climate change; (2) crop yields decrease, but to an extent that can be countered with improvements in breeding and farming practices; (3) crop yields decline to an extent that will require major changes to the agricultural systems and perhaps the human population. The mechanisms that shift an area from one category to the next will be both ecological and institutional.

Nelson et al (2009) estimate costs of climate change adaptation in SSA at nearly three billion dollars. Their cost estimate is not differentiated by crop. The costs of maize adaptation alone would be somewhat smaller, though certain adaptations (such as infrastructure investments) cannot be assigned to a specific crop or sector.

Research and Development

Most tropical maize is grown for subsistence and provides little incentive for private sector research and development.[57] Maize that performs well in temperate regions does not generally thrive in tropical regions to the same extent; it cannot be introduced directly into tropical regions without undergoing extensive adaptive breeding.[58] Improved seed varieties developed for use in temperate regions are of limited use to maize farmers in developing countries. Improvements are therefore almost entirely reliant on public sector research and development, national policies, and household-level adaption efforts.[59]

The Agricultural Science and Technology Indicators initiative surveyed government agencies, NGOs, and private sector researchers in 26 countries in SSA. They identified 3570 full-time equivalent crops researchers, of which 300 (8%) were focused on maize.[60] The only single crop with a similar share of dedicated FTEs is rice, with 7% of all FTEs identified. However, there does not appear to be a relationship between maize yields or maize production and number of FTE maize researchers by country.

The Consultative Group for International Agricultural Research (CGIAR) research centers are drivers behind a large portion of crop development research. Of the 15 CGIAR centers (not including BMGF) the International Maize and Wheat Improvement Center (CIMMYT) is the main agency for maize research, and the International Institute for Tropical Agriculture (IITA) has a maize initiative as well. Other CGIAR centers conducting maize research include Bioversity, the International Center for Tropical Agriculture (CIAT), and the International Food Policy Research Institute (IFPRI). The CGIAR also funds some maize research through the Generation Challenge Programme, a multi-crop and multi-center plant breeding and improvement effort.

The Improved Maize for African Soils initiative (IMAS) is a new public-private partnership between CIMMYT, Pioneer Hi-Bred, and the agricultural research agencies of Kenya and South Africa. The project aims to develop and disseminate improved maize seed varieties at low cost, but the focus is on low-nitrogen tolerant varieties rather than on climate-stress tolerant varieties. IMAS is funded by $19.5 million in grants, along with significant in-kind contributions from the research partners.[61]

National Adaptation Plans of Action

As part of the Least Developed Countries Work Programme, 31 countries in SSA have submitted National Adaptation Plans of Action (NAPAs) proposing climate change adaptation projects to address urgent national needs.[62] While the priority projects and specific aims vary by country, there are common themes, such as (1) promoting small-scale irrigation; (2) breeding and disseminating improved or local varieties, particularly short-cycle or drought-tolerant varieties; (3) improving crop management and (4) crop or livelihood diversification. While the above activities are mentioned in almost every NAPA, 9 of the 31 NAPAs propose those activities specifically in the context of maize production. An additional 6 of 31 countries mention maize specifically throughout the NAPA, but do not explicitly target maize in their proposed activities.[63]

The relevance of maize-specific proposals is limited by the fact that some countries face financial or political obstacles to action, and many countries do not have the capacity to implement and monitor new policies outlined in their NAPAs. Specific obstacles include: weak involvement of local communities; weak coordination amongst stakeholder involved; delays in allocating funds; weak network of extension services and technologies; lack of access to infrastructure and markets; and insufficient research and development capacity.[64]

Conclusion

Maize has been and is likely to remain an important food crop in SSA. Projected increases in temperature and possible changes in precipitation are likely to reduce maize production and yield, especially in areas where production is already marginal. Maize receives high levels of R&D funding, but country-level economic and infrastructure constraints may hinder adaptation efforts.

Please direct comments or questions about this research to Leigh Anderson, at eparx@u.washington.edu

Appendix 1. Maize Production & Trade in Tonnes, Compared to All Cereal Production

	Maize Production	Net Trade (Exports – Imports)	Maize Production as % of Total Cereal Production
Angola	615894	-7060	87.40%
Benin	931598	0	80.40%
Botswana	12000	-35023	30.14%
Burkina Faso	553874	0	17.82%
Burundi	115507	0	39.63%
Cameroon	1200000	-72500	62.32%
Cape Verde	3068	-1580	100.00%
Central African Republic	139776	-422	59.08%
Chad	201257	-7012	10.21%
Comoros	4000	-36	16.67%
Congo	8000	-6873	40.00%
Côte d'Ivoire	531940	0	42.77%
Democratic Republic of the Congo	1155720	-11457	75.79%
Djibouti	10	-454	100.00%
Equatorial Guinea		0	0.00%
Eritrea	13686	969	2.96%
Ethiopia	3336795	-31895	28.17%
Gabon	33000	-342	96.77%
Gambia	31408	0	20.86%
Ghana	1219600	0	72.91%
Guinea	595460	0	22.89%
Guinea-Bissau	13907	0	7.56%
Kenya	2928793	-65440	81.03%
Lesotho	60312	-120	82.98%
Liberia		0	0.00%
Madagascar	370000	-6545	10.94%
Malawi	3226418	371075	93.79%
Mali	689918	0	17.76%
Mauritania	16966	0	9.25%
Mauritius	1021	-74168	100.00%
Mozambique	1152050	-9027	79.24%
Namibia	60000	2376	41.96%
Niger	19300	0	0.50%
Nigeria	6724000	0	24.75%
Rwanda	102000	-43742	28.98%
Sao Tome and Principe	3000	-5	100.00%
Senegal	158266	0	20.49%

Seychelles		-8515	0.00%
Sierra Leone	48000	0	4.37%
Somalia	99000	-40441	50.52%
South Africa	7125000	-1162445	74.89%
Sudan	70000	-27430	1.05%
Swaziland	26170	-100165	95.98%
Togo	546050	0	62.22%
Uganda	1262000	46844	47.97%
United Republic of Tanzania	3659000	80467	58.80%
Zambia	1366158	4761	88.87%
Zimbabwe	952600	-398806	74.81%

Source: FAOSTAT (2007 data)

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