Chapter 2. Climate Scenarios in Relation to Agricultural Patterns of Major Crops in Southern Africa

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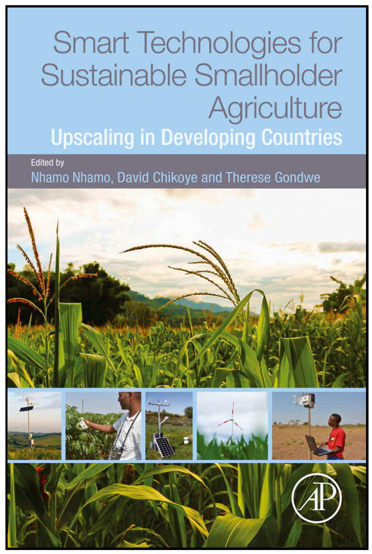

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CHAPTER 2

Climate Scenarios in Relation to Agricultural Patterns of Major Crops in Southern Africa

Paramu L. Mafongoya[1], Kabir Peerbhay[1], Obert Jiri[2], Nhamo Nhamo[3]
[1]University of KwaZulu–Natal, Pietermaritzburg, South Africa; [2]University of Zimbabwe, Harare, Zimbabwe; [3]International Institute of Tropical Agriculture (IITA), Southern Africa Research and Administration Hub (SARAH) Campus, Lusaka, Zambia

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2.1 INTRODUCTION

Agriculture in southern Africa plays a critical role in the formal and informal economy (Chen, 2005). Agriculture is critical in sustaining rural livelihoods and food security (Godfray et al., 2010; Vermeulen et al., 2012; Lobell et al., 2008). Agriculture is directly dependent on climatic factors such as solar radiation, temperature, and precipitation. Therefore climatic variability dictates the potential of crop and livestock production systems in general

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and more specifically the regions or locations suitability, the characteristics of cultivars and breeds to be used, range of options from which choices can be made, and the cropping calendars to follow (Tingem and Rivington, 2009; Unganai and Kogan, 1998). The agricultural sector is inherently sensitive to shifts in climate; hence the need to manage some of the uncertainties. Changes to the climatic variables may alter agricultural productivity in general, crop yield, and livestock potential leading to altered food production pattern in various ways (Davis, 2011; Rosenzweig et al., 2001). Table 2.1 summarizes the impacts of these climatic shifts to agricultural production in southern Africa.

Climate change is the long-term shift and fluctuation in the statistics of weather patterns of an area as reflected in weather parameters such as precipitation, temperature, humidity, wind, and seasons (IPCC, 2007; Ngaira, 2007). The natural variability has been found to play a subsidiary role in recent climate changes compared to the anthropogenic increase in GHG (Crowley, 2000). All these climatic conditions are likely to pose new challenges for various farming systems, crops, and regions (Fischer et al., 2005). With 2°C increase in temperature and 10% reduction in rainfall, the maize yield in southern Africa is expected to experience a reduction of 0.5 t/ha (Schulze, 2007). The greatest impact of production is expected to be in most marginal areas where rainfall is low and irregular irrigation is practiced. Smallholder agricultural systems are at high risk due to high dependence on rainfed agriculture as well as fewer capital resources and management technologies available to them. It is critically important to identify the full set of drivers changing agricultural productivity that tends to be complex and integrated at various levels.

Despite this, a decline in crop production as a result of climate change is likely to adversely affect food security because it will increase food prices. Southern Africa is likely to be impacted by future climate change as the latest climate change projections for the region indicate that both temperature and evapotranspiration are likely to increase in the 21st century. Climate change is likely to alter the magnitude, timing, and distribution of storms, which produce flood events as well as frequency and intensity of drought events (Fauchereau et al., 2003).

Southern Africa has existing critical vulnerability that exacerbates the effects of future climate change in most sectors due to their dependence on the natural environment and resources for livelihoods. Recurring hazards lead to both direct and indirect and secondary impacts on society and agricultural systems. Direct losses are defined here as the actual financial value

Table 2.1 Direct and indirect impacts of projected climate change on crop and livestock production and the socioeconomic implications to communities living in southern Africa

Production system	Nature of impact	Description of effect	References
Crop production	Direct impacts	• Even small increases in mean temperature of between 1 and 2°C are projected to lead to a decrease in crop productivity • Changes in temperature regimes could affect growing locations, the length of the growing season, crop yields, planting and harvest dates • Increased need for irrigation in a region where existing water supply and quality is already negatively affected by other stressors • Ecological hazards of droughts desertification and soil erosion may worsen making the areas unsuitable for crop production	Davis (2011), Mirza (2003), Ngaira (2007), Rosenzweig et al. (2001) and Unganayi and Kogan (1998)
	Indirect impacts	• Predicted higher temperatures are likely to negatively impact organic matter, thereby reducing soil nutrients • Higher temperatures may favor the spread of significant weeds, pests, and pathogens to a range of agricultural systems	
Livestock production	Direct impacts	• Changes in forage quality and quantity (including the availability of fodder crops) • Changes in water quality and quantity • Reduction in livestock productivity by increasingly exceeding the temperature thresholds above the thermal comfort zone of livestock, which could lead to behavioral and metabolic changes (including altering growth rate, reproduction, and ultimately mortality) • Increased prevalence of "new animal diseases" • Increases in temperature during the winter months could reduce the cold stress experienced by livestock, and warmer weather could reduce the energy requirements of feeding and the housing of animals in heated facilities	McMichael et al. (2007), Pelletier and Tyedmers (2010) and Thornton (2010)
	Indirect impacts	• Increased frequency of disturbances, such as wild fires • Changes in biodiversity and vegetation structure	
Socioeconomic/livelihood impacts		• Changes in incomes derived from crop and livestock production • Shifts in land use (including consequences of land reform) • Overall changes in food production and security	Ngaira (2007), Fischer et al. (2005)

of damage to and loss of capital assets, whereas secondary includes disruption of development plans, increased balance of payment deficits, increased public sector deficits and debt, and worsened poverty levels. Secondary impacts relate to the short- and long-term impacts on aggregate economic performance (Benson and Clay, 2000).

Understanding these climatic changes and their possible impacts on society are thus essential in critical sectors in southern Africa to improve strategic adaptation responses.

2.2 SOUTHERN AFRICA IN CLIMATE CHANGE AND HISTORICAL CHANGES

Four broad climatic zones have been used to describe Africa based on a combination of precipitation, temperature, and evapotranspiration, i.e., (1) arid and semiarid (Sahel region, Kalahari and Namib deserts), (2) tropical savanna grasslands (Sahel, Central, Southern Africa), (3) equatorial (The Congo region and the East African highlands), and (4) temperate (The Southeastern tip of South Africa) (Ngaira, 2007). Southern Africa is predominantly a semiarid region with high rainfall variability. The region is characterized by frequent droughts and floods. Work of Unganai and Kogan (1998) has shown recurrence of drought in the region during the 1982–4, 1991–2, and 1994–5 season, which led to massive crop losses. The region is also widely recognized as one of the most vulnerable regions to climate change because of low levels of adaptive capacity especially in rural communities combined with a high dependence on rainfed agriculture (IPCC, 2007). The use of weather forecasting in agricultural planning has remained low albeit its critical role. Furthermore, the current trend of investment in southern Africa has focused more on recovery from droughts and other disasters at the expense of developing the adaptive capacity of communities with high risk (Mirza, 2003).

The climate of southern Africa is strongly determined by the Pacific air circulation of the subcontinent in relation to the major circulation patterns of the southern hemisphere, complex regional topography, and the surrounding ocean movements. The resounding effect of these air mass circulations has explained in part some of the precipitation and temperature patterns observed in the region.

2.2.1 Rainfall

The region is described as predominantly semiarid with high seasonal and interannual rainfall variability. Extreme events such as droughts and floods occur frequently. The amount and seasonal distribution of rainfall are the most critical factors to consider when looking at rainfall across the region. There is a high degree of spatial variation in rainfall across the region. The average rainfall in the region is less than 1000 mm per year based on the period 1901–2009. Rainfall tends to decrease to the northeast and to the southwest (Fig. 2.1). Highest rainfall occurs in the highlands of eastern Madagascar, which receive 3100 mm per year. The majority of the region receives between 500 and 1500 mm per year, with more semiarid regions of the south receiving between 250 and 500 mm per year (Fig. 2.1). Rainfall over most of southern Africa is moderately seasonal. The majority of the rainfall occurs in the summer months of the year between October and March.

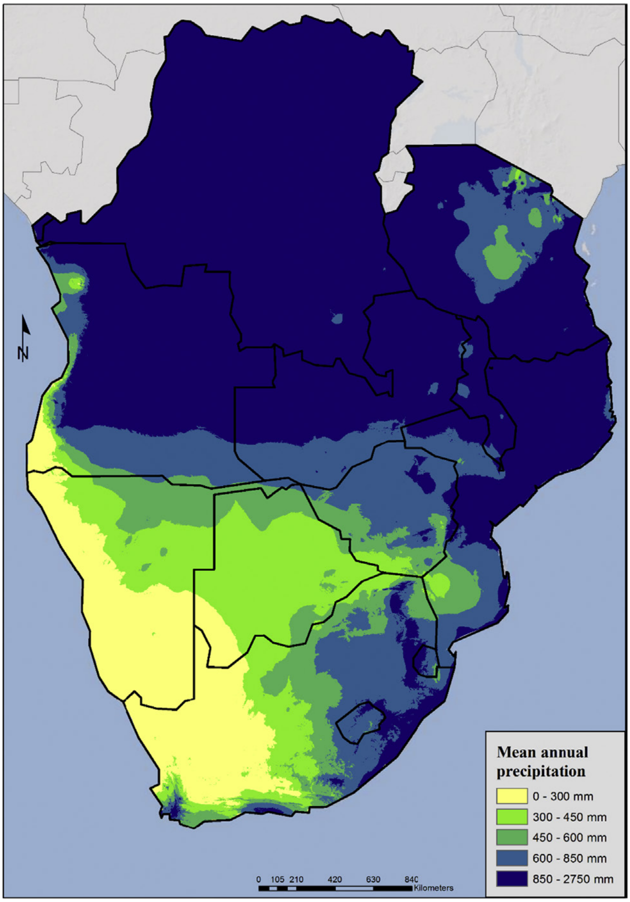

Figure 2.1 Mean annual rainfall for southern Africa (1901–2009). *Source: WorldClim—World Climate Data.*

Southern African interannual rainfall variability is known to be linked to the El Nino Southern Oscillation (ENSO) phenomenon. During the warm ENSO events dry conditions generally occur over much summer rainfall regions of southern Africa. In 1982/1983 below average rainfall and droughts in many parts of the region coincided with serious El Nino event. The influence of El Nino is strongest in the southeastern parts of the region and reaches a maximum in the last summer from January to March (2016). Other important determinants of rainfall patterns in southern Africa include the Inter-Tropical Convergence Zone (ITCZ). The ITCZ is a region characterized by high convergence activities resulting in high rainfall in several countries in summer months when its position shifts to the southern hemisphere.

2.2.2 Temperature

Southern Africa has a warm climate and much of the region experiences average warm temperatures above 17°C. Across the region mean annual minimum temperatures range from 3 to 25°C and mean annual maximum temperatures range from 15 to 36°C (Fig. 2.2). Frost is common in winter months on the central plateau and high altitude areas such as in South Africa and Zimbabwe. The greatest decrease in temperature is observed over the central plateau regions and the highland areas where the range difference can be 19°C. The coldest temperatures are experienced over South Africa, extending to southern parts of Namibia where temperatures average less than 15°C. Across the region average temperatures are mostly determined by a combination of latitude, elevation, and proximity relative to the coastlines of Indian and Atlantic Oceans (Chevalier and Chase, 2016).

2.3 CLIMATE CHANGE TRENDS IN SOUTHERN AFRICA

One of the best ways to understand how southern Africa regional climate may change in the future is to examine how it has changed in the past. This can be done by examining the observational records in southern Africa for evidence of climate trends over the last century.

2.3.1 Long-Term Observations

Climate observations are models used to determine changes in climate. However, most rural communities in southern Africa have always relied on indigenous knowledge systems to help them deal with climate variability

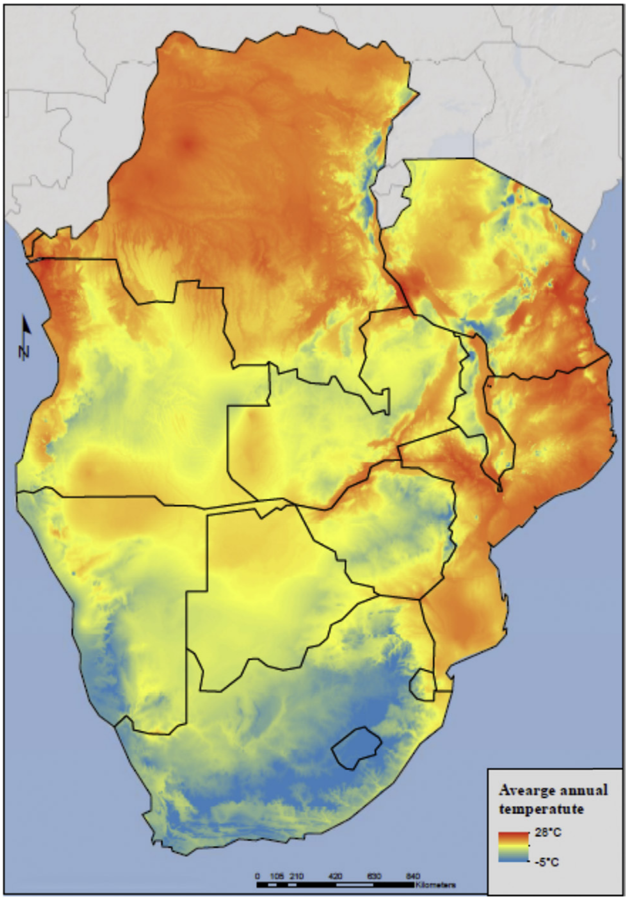

Figure 2.2 Mean annual temperature for southern African (1901–2009). *Source: WorldClim—World Climate Data.*

and change (Jiri et al., 2015). A key question when dealing with indigenous knowledge is how it can be integrated successfully with scientific knowledge to develop climate mitigation and adaptation strategies.

2.3.2 Temperature

There is strong evidence based on analysis of mean and maximum temperature trends that the region is getting warmer. These trends are shown in Fig. 2.3. From the 1970s these anomalies were almost persistent, approximately 0.8°C above the 1901–90 averages. The anomalies are also larger in more recent years, suggesting that the rate of increase in minimum and

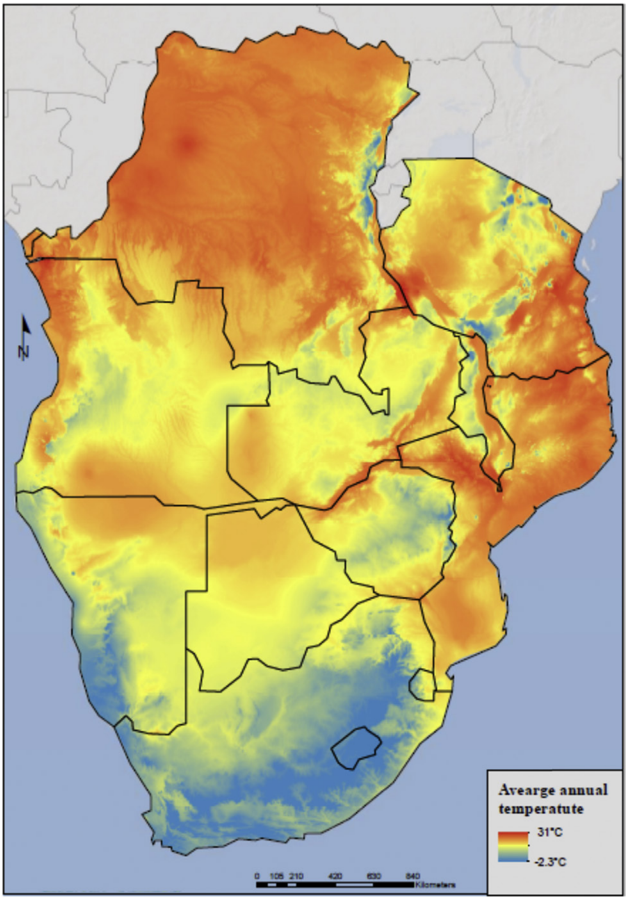

Figure 2.3 Projected mean annual temperature for southern Africa (2050). *Source: WorldClim—RPC 8.5, 2050.*

maximum temperatures is increasing (Jiri et al., 2015). These observations are consistent with detected increases in global annual air surface temperatures over southern Africa since 1900s (Kruger and Shongwe, 2004).

Trend analysis of temperatures across southern Africa reveals that annual minimum and maximum temperatures have increased at an average rate of 0.057°C per decade and 0.046°C per decade, respectively, between 1901 and 2009. Further analysis reveals that the periods of most rapid warming occur post-1990, a period for which the rate of increase for both average annual minimum and maximum temperatures is statistically significant.

After 1976, minimum temperatures began increasing by 0.27°C per decade and maximum temperatures by 0.25°C per decade (Davis, 2011). The larger rate of increase in minimum temperatures has been observed before (Alexander et al., 2006). Studies showed a general trend toward less severe cold events. After 1995, the highest observed maximum temperatures began to increase at a rate of 0.85°C, suggesting that the frequency of hot years is increasing.

2.3.3 Rainfall

Changes in rainfall are cryptic and difficult to detect. This is due to the fact that rainfall varies from place to place and from year to year across southern Africa. Existing evidence suggests no decrease in annual rainfall over southern Africa, however, certain characteristic of precipitation varied significantly across locations (Kruger, 2006). Other evidence has shown that interannual amount variability over southern Africa has increased since the late 1960s and droughts have become more intense and widespread in the region (Fauchereau et al., 2003). The pattern of anomalies shows that year-to-year rainfall variability is high across the region and has been a persistent feature of the region's climate for many years. The alternating patterns of above-normal and below-normal rainfall scenarios clearly illustrate that rainfall cycles fluctuate in the region. Extreme wet and dry years have been recorded, which resulted in floods and droughts. In 1999–2000 tropical cyclone Eline caused widespread flooding in southern and central Mozambique, southeastern Zimbabwe, and parts of South Africa and Botswana. In 1982–3 (El Nino year), 1986–7, and 1991–92 serious droughts were experienced that caused a decrease in crop and livestock production in many parts of the region (Vogel, 1994). The ENSO cycle is highly likely to be the main force responsible for many of the teleconnections in southern Africa rainfall patterns. This phenomenon though evident in southern Africa is absent or insignificant in other regions. In instances where records are available for a long time, there have been detectable increases in the number of heavy rainfall events. Studies in the regions have shown that the length of dry seasons and rainfall intensity have increased.

Over southern Africa there is evidence to suggest that temperatures have been increasing over the last century and that the rate of warming has been increasing, most notably in the last two decades. No clear evidence exists for changes in mean rainfall. The rainfall time series remain dominated by patterns of interannual rainfall variability.

2.4 FUTURE CLIMATE SCENARIOS OVER SOUTHERN AFRICA

A scenario is an incoherent, internally consistent, and plausible description of a possible future state of the world. It is not a forecast, rather scenario is an alternative of how the future can unfold (Davis, 2011). A set of scenarios is often adopted to reflect the possible range of future conditions, which can be based on changes in the climate system, socioeconomic circumstance, or other future changes (Davis, 2011).

2.5 DETERMINING FUTURE CLIMATE SCENARIOS

The Global Circulation Models (GCM) are the fundamental tools used for assessing the causes of past changes and inferring future changes. These are complex models based on the laws of physics, which represent interaction between the different components of the climate system such as the land surface, the atmosphere, and the oceans. Because future levels of greenhouse gas emissions in the atmosphere are dependent on the behavior or policy changes, whether or not we continue to depend on fossil fuels or switch to renewable energy sources, the models simulate climatic changes under a range of emission scenarios. Each scenario represents a plausible future. That there is a range of future possibilities which is an important concept in understanding clearly as it means that we can only suggest futures that maybe more likely than others.

The spatial resolution of GCM is too low to accurately represent the circulation patterns that determine climate at regional and local scales. To generate more detailed simulations at regional and local climate, two main types of downscaling methodologies maybe employed. These are statistical (empirical) and dynamical downscaling methods. Downscaling is the term used to describe the process through which the projections of change from GCMs are translated to the regional and local scales. The downscaled scenarios at a finer spatial scale are more useful for assessing local and regional impacts, adaptation, and developing policies.

2.5.1 Rainfall

Most scenarios generated by GCMs suggest the delay in the main rainfall season for large parts of southern Africa and increase in incidences of droughts over central southern Africa. Majority of the models are simulating a decrease in rainfall over most of the region (Fig. 2.4). There is also

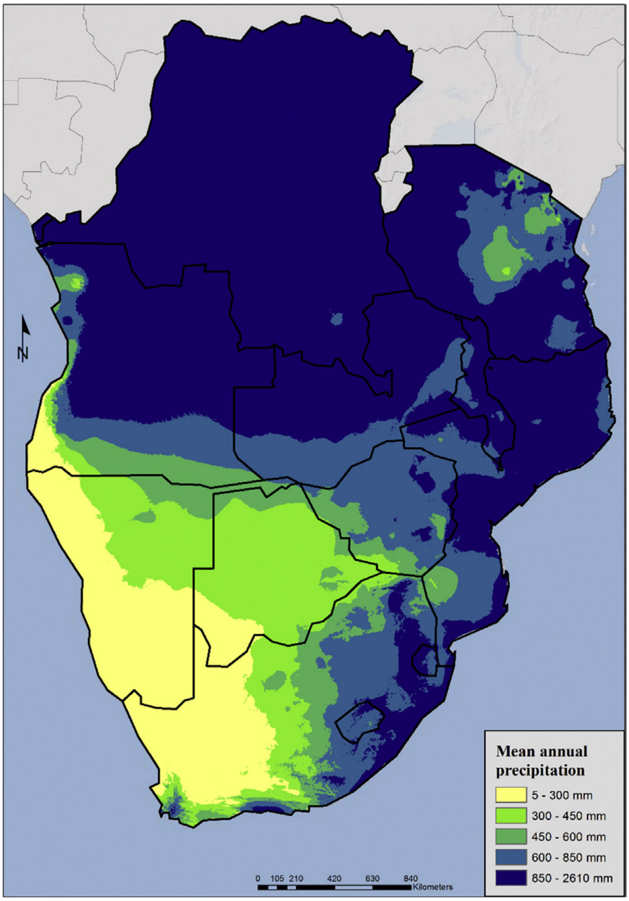

Figure 2.4 Projected mean annual precipitation by 2050. *Source: WorldClim—RPC 8.5, 2050.*

consistent simulated decrease in rainfall during summer across much of southern Africa. This is the period encompassing the start of the rains and suggests a reduction in early season rainfall.

2.5.2 Temperature

The models showed an increase in temperature under various scenarios of (greenhouse gas(es)) GHG emissions. Temperatures are expected to rise between 1 and 3°C. The weather of southern Africa is warming about twice the rate of global average (Scholes et al., 2015).

2.6 PROJECTED CHANGES IN EXTREME WEATHER EVENTS OVER SOUTHERN AFRICA

Climate change may manifest itself not only through changes in the long-term mean rainfall, temperature, and circulation patterns, but also through the increase in the frequency and intensity of extreme weather events. The concentration of GHGs in the atmosphere has enhanced the ability of the atmosphere to absorb and hold moisture. The excess heat and moisture can lead to increases in the frequency of extreme weather events such as tropical cyclones and heat waves. The intensity of tropical cyclones has been projected to increase. A general increase in extreme rainfall events are projected for southern Mozambique. Southern Africa is projected to become generally warm and increased average temperatures are projected to occur in association with increase in very hot days with maximum temperatures exceeding 35°C and associated increases in heat waves.

The key areas of agreements between different models, GCMs, statistical downscaling, and dynamical downscaling are shown in Table 2.2. All three models show an increase in projected temperatures; increase in mean minimum and maximum temperatures are indicated as consistent and robust with a minimum projected change of 0.3°C and maximum at 3.6°C. All the models show increase in very hot days or heat waves during summer months. Rainfall is consistently suggested to decrease over parts of Zimbabwe, Zambia, and western Mozambique. A decrease in winter and spring rainfall over southwestern parts of South Africa is indicated in most simulations, whereas southeastern South Africa generally receives more rainfall.

2.7 IMPACTS OF FUTURE CLIMATE SCENARIOS ON CROPS AND LIVESTOCK PRODUCTIVITY

Higher temperatures, variable rainfall, shifting seasons and extreme weather events, flooding and droughts will significantly challenge future agricultural production in most parts of southern Africa. In countries such as South Africa, which are dry, averaging 450 mm of rainfall, water is a critical issue. In (Southern Africa Development Community) SADC countries about 60–70% of water sources are used for agriculture. Global warming and associated changes in rainfall patterns are beneficial in some areas for agriculture, especially cool areas, e.g., highlands where temperatures are low for crop production (Scholes et al., 2015).

Every crop and animal has an optimal temperature optimum for growth and yield. For most crops and livestock, this is in the range of

Table 2.2 Comparison of climate change projections from the Global Circulation Models (GCMs) and the two downscaling techniques for southern Africa

	GCM	Statistical downscalings	Dynamical downscalings	Reference
Time scale	1960–2000 2030–2060	1961–2000 2036–2065	1961–2000 2036–2065	Davis (2011)
Rainfall	Decrease over central and western southern Africa	Increases over Angola, northern Mozambique and southeast South Africa during Dec., Jan., Feb. and Mar., Apr., May	Decrease in rainfall projected for western southern Africa	
	Decrease over most of southern Africa during September, October, November, and southwest South Africa during June, July, August	Decrease over Zimbabwe, Zambia, western Mozambique and parts of the southwestern coastline during Dec., Jan., Feb., and Sep., Oct., Nov.	Increases over south east South Africa	
Temperature	Increase in mean, minimum, and maximum temperature 1–3°C	0.8–3.6°C	0.3–3.2°C	
Extreme weather events	Increases in very hot days and heat waves	Increases in very hot days and heat waves	More extreme rainfall events over eastern southern Africa. Increase in very hot days—above 35°C	

Source: Davis, C., 2011. Climate Risk and Vulnerability: A Handbook for Southern Africa. CSIR, Pretoria. 92p. Available online at: www.rvatlas.org/SADC.

25–30°C (Scholes et al., 2015). Places where the growing season temperature is warmer than this will experience lower production as temperature rises. Whereas cooler places than optimum will benefit from warming. Mean global temperatures of up to 2°C above the preindustrial time will result in balanced food production globally. Above 3°C of warming, overall global agricultural production is projected to fall steadily. Southern Africa is warming at above the rate of global average, and mostly already above the temperature optimums. Southern Africa, therefore, falls into the category of a region where agricultural production will be negatively affected overall.

2.7.1 Crop Production

Maize and wheat production in southern Africa is projected to decrease considering direct effects above. For South Africa each 1% decline in rainfall translates to 1.1% decrease in summer maize production and a 0.05% decrease in winter wheat. Each 1°C increase in temperature results in a 5% decrease in maize and wheat production (Scholes et al., 2015). Already the climate of large swaths of Namibia, Botswana, Lesotho, and smaller proportions of Swaziland and Zimbabwe are unsuitable for maize production. The agricultural prospects of Swaziland, Botswana, Namibia, and Zimbabwe are worrying. Substantial decreases in the productivity of crops-suitable land in Namibia, Botswana, South Africa, and Zimbabwe are projected. Parts on Angola, Malawi, Mozambique, Zimbabwe, and Madagascar are also projected to experience declines in crop production under climate change. The agricultural outlook for Angola, southern Democratic Republic of Congo, Zambia, Mozambique, and Tanzania are potentially positive even under climate change. Decreasing crop production as temperature rises could be offset by improved agricultural practices, and the areas are broadly expected to experience more rainfall under climate change.

Cropping systems will tend to develop around their capacity to produce relatively higher yields and at the same time adapt to low rainfall, extreme cold, and/or hot temperatures and high evapotranspiration rates. Crop with drought, heat, and cold stress tolerance will dominate the markets and diets of people in southern Africa especially the borderline income group (those with income not significantly different from the poverty datum line). An increase in the area under irrigation will save huge amounts of money, which would otherwise go toward imports of processed and raw food products. Crops such as cassava will feature more prominently on the farms as they tolerate a range of stresses, and the produce has multiple uses. In areas where maize just survives at present there is a likelihood that no maize will be produced especially where the existing desserts will expand northwards in Botswana and Namibia and parts of Angola.

2.7.2 Livestock Production

Livestock (cattle, sheep, goats, pigs, and poultry) maintain their body temperature at between 36 and 38°C. As outside temperature approaches this fixed body temperature they must stay in shade instead of feeding, leading to less energy available for growth. Prolonged exposure to high temperatures without adequate water leads to livestock death. Heat stress is particularly a problem in dairy cows. Meat production, milk production, and fertility in livestock fall steeply when daytime temperatures exceed 30°C (Scholes et al., 2015). Therefore, the prospects of livestock production in the hot, arid parts of southern Africa under climate change look bleak.

The majority of climate models as shown in other sectors of southern Africa indicates a likely increase in average minimum and maximum temperatures. Increased temperatures impact on livestock production in a variety of ways. Heat stress can impact on food intake, fertility, live weight gain, and mortality. Different breeds have different thresholds above which they experience heat stress. Local breeds are more resistant to high temperatures. The more the temperate, breeds such as Holstein (*Bos taurus*) tend to experience heat stress above 22°C (Sanchez et al., 2009). It is clear that livestock farming under climate change in southern Africa will have to take cognizance of the existing knowledge around more traditional breeds and livestock management knowledge. Moonga and Chitambo (2010) propose that well-adapted traditional livestock breeds will play a significant role in adaptation to climate risk in southern Africa. The increased need for genetic conservation of these breeds cannot be overemphasized. However, the impacts of climate change on the livestock sector in southern Africa are an area requiring further research.

2.8 CONCLUSION

As temperature and rainfall patterns change throughout southern Africa, the areas most suitable for various crops will either expand or shrink and in some cases shift. That does not mean automatically that they will be worse off. They can adapt through developing heat or drought-tolerant varieties within a given crop or animal species. So far it has been difficult

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to exploit the upper temperature niches for plants or animals or exploit the water-use efficiency of plants. Where temperatures limit water use by fundamental physiological processes, even advanced technologies such as genetic modification will not help much to alter them. Agronomic practices or livestock practices, which are climate smart will be a key requirement for success. These technologies will reduce agricultural losses and at the same time limit the impacts of weeds, pests, and diseases of both crops and livestock.

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