ISSD Africa

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Climate-resilient seed systems & access and benefit-sharing in Zimbabwe:
Exchanging Genetic Resources in a Changing Climate

Thematic Working Group 3
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ACRONYMS

ABS	Access and benefit sharing
AER	Agro-ecological region
AFSTA	African Seed Trade Association
AGRITEX	Department of Agricultural, Technical and Extension Services (of the Ministry of Agriculture, Mechanization and Irrigation Development of Zimbabwe)
ARC	Agricultural Research Council, South Africa
AU	Africa University
A4NH	Agriculture for Nutrition and Health (CGIAR Research Program)
CA	Conservation agriculture
CBD	Convention on Biological Diversity
CBI	Crop Breeding Institute
CBO	Community-based organization
CCAFS	Climate Change, Agriculture and Food Security
CFS	Climate field school
CIMMYT	International Maize and Wheat Improvement Center
CRP	CGIAR Research Program
CRS	Chiredzi Research Station
CwDCC	Coping with Drought and Climate Change project
DARS	Department of Agricultural Research Services, Malawi
DRSS	Department of Research and Specialist Services (of the Ministry of Agriculture, Mechanization and Irrigation Development, Zimbabwe)
DT	Drought tolerant
DTMA	Drought-tolerant maize for Africa
ENSURE	Enhancing Nutrition, Stepping-up Resilience and Enterprise
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus group discussions
GBZ	Gene Bank of Zimbabwe
GCI	Grain Crops Institute, South Africa
GCM	General circulation models
GEF	Global Environment Facility
GIS	Geographic information system
GRBI	Genetic Resources and Biotechnology Institute
HTMA	Heat-tolerant maize for Asia
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and communication technologies
IDS-NUST	Institute of Development Studies, National University of Science and Technology
IEA	Independent Evaluation Arrangement
IIA	Institute for Agricultural Research, Angola
IMAS	Improved maize for African soils (Kenya, South Africa, Zimbabwe)
IMOD	Inclusive market-oriented development
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
LFSP	Livelihoods and Food Security Project
LSU	Lupane State University
MAR	Melkassa Agricultural Research Centre
MLN	Maize lethal necrosis
MLS	Multilateral system of access and benefit sharing of the ITPGRFA
MoAMID	Ministry of Agriculture, Mechanization and Irrigation Development
MoEWC	Ministry of Environment, Water and Climate
ZMSD	Zimbabwe Meteorological Services Department

Nagoya Protocol	Nagoya Protocol Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity
NARS	National Agricultural Research System
NASFAM	National Smallholder Farmers' Association of Malawi
NGO	Non-governmental organization
NPGRC	National Plant Genetic Resources Centre
NUST	National University of Science and Technology
OPV	Open-pollinated varieties
PGR	Plant genetic resources
SADC	South African Development Community
SCF	Seasonal climate forecasting
SMTA	Standard Material Transfer Agreement
TK	Traditional knowledge
UMP	Uzumba Maramba Pfungwe (reference site)
UNDP	United Nations Development Programme
USDA	United States Department of Agriculture
UZ	University of Zimbabwe
VCU	Value for cultivation and Use
WEMA	Water-Efficient Maize for Africa
WUA	Women's University in Africa
ZimCLIFFS	Zimbabwe Crop-Livestock Integration for Food Security

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We also wish to acknowledge with appreciation the information received from stakeholders, breeding programmes, CGIAR centres, research projects and the various research institutes who contributed. The authors take responsibility for any omissions or errors.

CONTENTS

1. INTRODUCTION

Africa is one of the most vulnerable regions in the world to climate change, due to widespread poverty and the limited coping capacity of its population (IPCC, 2007a; 2013). Zimbabwe is particularly vulnerable owing to its heavy dependence on rain-fed agriculture and climate-sensitive resources. Agriculture's sensitivity to climate-induced water stress is likely to intensify the existing problems of decreasing agricultural outputs, declining economic productivity, poverty and food insecurity, with smallholder farmers in Zimbabwe particularly affected. Extreme weather events, notably drought, flooding and tropical storms, are also likely to threaten development gains across a variety of sectors such as agriculture. Climate change will cause spatial and temporal changes in precipitation and temperature that will result in shifts in the distribution of climates and land areas suitable for the cultivation of a wide range of crops. Studies indicate a general trend towards the loss of cropping areas in sub-Saharan Africa. Although farmers have always adapted their cropping systems to adverse environmental conditions, the speed and complexity of climate change pose problems on an unprecedented scale. Without adaptation and mitigation, climate change is predicted to negatively affect the production of the world's major crops in both tropical and temperate regions. There is evidence that climate change has already negatively affected crop yields in many regions of Africa (IPCC, 2014; Knox et al., 2012; Schlenker and Lobell, 2010). Climate change adaptation is therefore a principal need for farmers and for future food security. Specifically, IPCC (2007b, 2014) urges developing countries to prioritize climate change adaptation due to their higher vulnerability.

Improved crop varieties have considerable potential for strengthening the adaptive capacity of farmers in developing countries. Accessing crop and varietal diversity and changing crop varieties to those adapted to changing climatic conditions are major adaptation strategies farmers may opt for, with both improved and traditional varieties having an important role to play (FAO, 2010). Maintenance of high levels of inter- and intra-species diversity is a strategy to decrease vulnerability and enhance resilience to climate change and associated stresses. Adaptation in this context could include the maintenance and re-introduction of traditional varieties, the introduction and adoption of new species and varieties to access newly developed production niches, and the development of ways of ensuring that materials remain available, accessible (e.g. community seed banks) and adapted (e.g. participatory plant breeding). Seed systems are an important strategy for enhancing such resilience, as seed security has direct links to food security and to resilient livelihoods. For example, providing farmers with easily accessible and adaptable seed can facilitate cost-effective adaptation responses to changing conditions. However, building resilient seed systems remains relatively unexplored in research and practice, particularly in sub-Saharan Africa (McGuire and

Sperling, 2013). This paper has four main objectives: (i) it provides a snapshot of climate change and the challenges faced by Zimbabwean farmers; (ii) it analyses the exchange of genetic resources among different stakeholders and the development of climate-resilient varieties and their distribution to farmers; (iii) it presents a synopsis of future plant genetic resources (PGR) needs using case studies of two communities; and (iv) it offers insights into the policy and legal environment for the exchange and access of genetic resources in the country.

2. METHODOLOGY

The study used secondary information collected from various databases, publications, and breeding programmes in Zimbabwe to highlight the country's experiences with regard to climate change and access to and exchange of genetic resources. Climate and crop modelling tools were used to predict the adaptive capacity of given crops to expected changes in climate. The results of these modelling exercises can be used to design strategies to access and use crops and crop varieties that are expected to be better adapted to future climate changes in specific locations. The Climate Wizard tool (www.climatewizard.org), was used to assess how climate has changed over time and to project what future changes are likely to occur in the country (see Appendix A for a detailed description of the methodology used for analysing current and future climatic changes in Zimbabwe**)**. Since meaningful statistical representations of modelled future climate predictions are best achieved by examining a range of time rather than a single year, the time period 2040-2069 and 2070-2099 to describe the conditions predicted for the mid-century (2050s) and the end of the century (2080s), respectively. To assess the impacts of climate change on rain-fed agriculture in Zimbabwe, the AquaCrop crop-water productivity model was used, by running it with both historical and predicted future weather conditions in order to derive probabilistic projections of agricultural production impacts from climate change (see Appendix B).

Primary data from the National Gene Bank of Zimbabwe (GBZ), breeding programmes and databases such as GENESYS[1], were used to analyse trends in the exchange of genetic resources within the country, in the region and internationally, including all the information available on the crops involved, quantity exchanged, purpose of these exchanges, the kind of agreements existing during the period of exchanges, and any conditionalities (if any) that existed during the exchanges. Key informants also provided insights into important issues such as the benefits of plant genetic resources (PGR) exchange; challenges and opportunities in implementing ABS for PGR; and the policy and legal environment for the exchange of PGR. The key informants included a senior breeder and a

[1] Global portal to information on plant genetic resources for food and agriculture. Available at https://www.genesys-pgr.org/welcome, accessed 10 January 2017.

seed scientist from the International Maize and Wheat Improvement Center (CIMMYT), a gene bank manager and country director from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ten breeders/managers from seed companies and the National Agricultural Research System (NARS), including the heads of the Crop Breeding Institute (CBI) and the Genetic Resources and Biotechnology Institute (GRBI) of Zimbabwe (see Appendix C). Face-to-face interviews were conducted with the key informants to provide answers to the following questions:

1. What has worked well in terms of exchanging genetic resources and accessing or developing benefits? Highlight any challenges that have been faced.
2. What are the policy initiatives needed to remedy the above challenges?
    - Are there any policy-level processes currently under way to facilitate the exchange of plant genetic resources for food and agriculture (PGRFA) and related information, and to make benefit sharing easier?
3. Indicate whether:
    - Zimbabwe has ratified the Convention on Biological Diversity (CBD), the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (Nagoya Protocol), and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA).
    - The above agreements have been domesticated and are being implemented.
    - The implementation of the above could be part of a solution to the challenges faced in smallholder seed systems.

Case studies were used to provide anecdotes on exchanges of PGRFA and related information that occurred between and among different stakeholders, such as private sector seed companies and communities; exchanges between communities; and exchanges between breeders in the region and internationally.

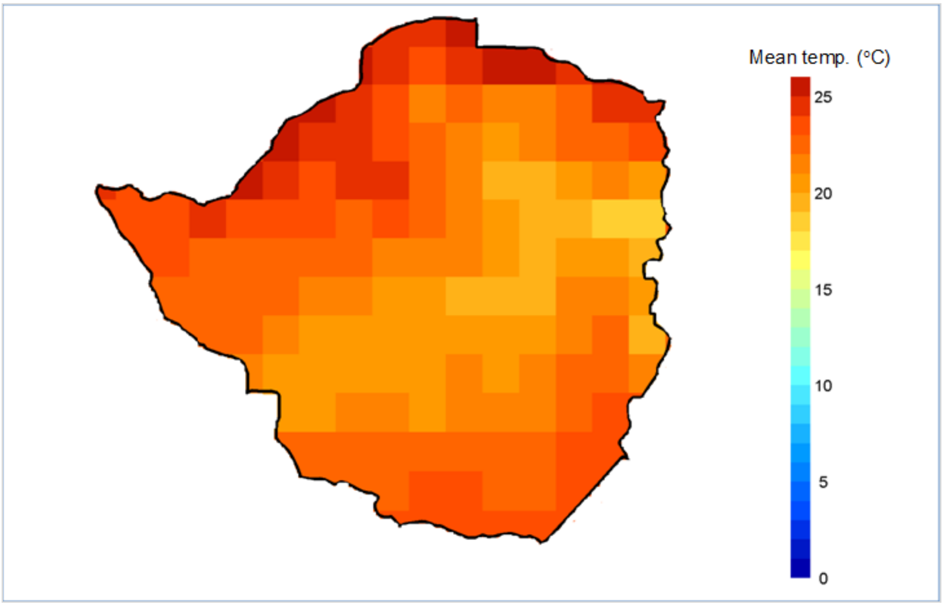
Finally, climate and GIS crop suitability modelling was used to analyse the present and future PGRFA needs of two communities in Zimbabwe. Two reference sites, namely Tsholotsho and Uzumba Maramba Pfungwe (UMP), were selected based on their different agro-ecologies, and their similar exposure to climate-related challenges such as drought and food insecurity. The research strategy involved a step-by-step methodology combining various participatory approaches and modelling tools to identify climate-related challenges, and available PGRFA and their use among communities in relation to climate change. Potentially adaptable materials were identified using modelling tools and data from national and international gene banks.

3. CLIMATE CHANGE AND RELATED IMPACTS ON CROP PRODUCTIVITY

3.1 Mean climate and historical climate trends

It is important to evaluate how climate has changed in the past. The monthly mean historical rainfall and temperature datasets can be mapped to show the baseline climate and seasonality by month, for specific years, and for rainfall and temperature. Figures 1 and 2 show the spatial distribution of the historical mean annual temperature and rainfall for Zimbabwe during the period 1951 - 2002.

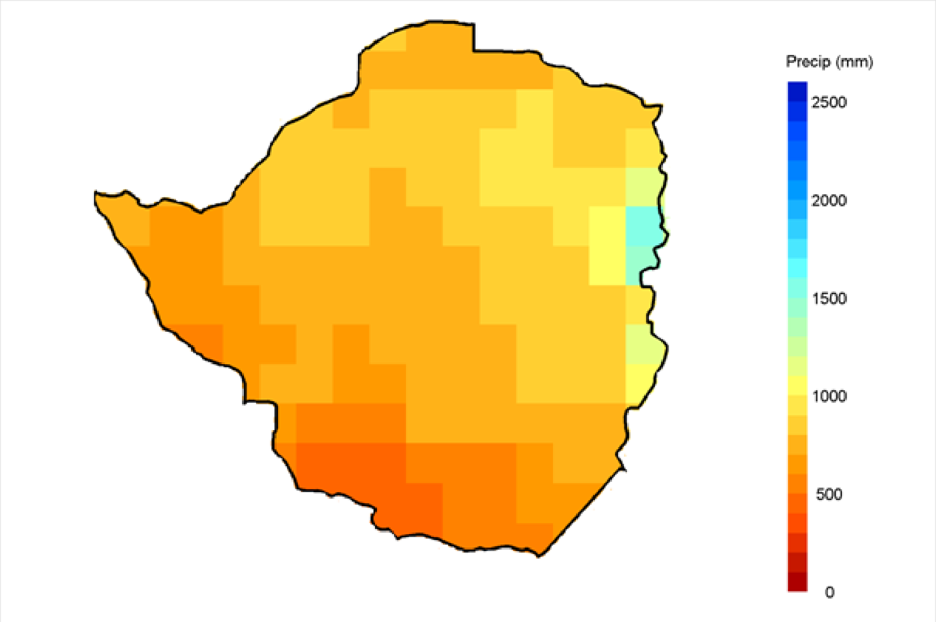
Figure 1. Mean annual temperature, Zimbabwe (1951 - 2002)



Source: Climate Wizard©[2]

[2] Figures 1 and 2 were developed using Climate Wizard, University of Washington and the Nature Conservancy, with base climate data from the Climate Research Unit (TS 2.10), University of East Anglia (UK). Climate Wizard is available at http://www.cru.uea.ac.uk, accessed 25 March 2017.

Figure 2. Annual mean precipitation, Zimbabwe (1951 - 2002)

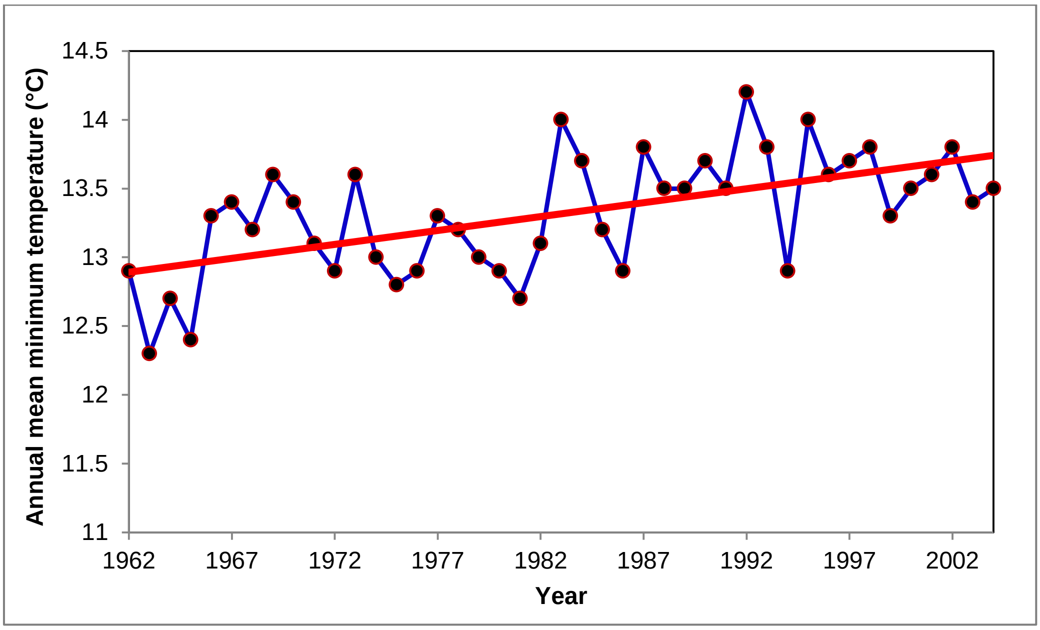


Source: Climate Wizard

The mean annual temperature for the period 1951 - 2002 across the country ranges from about 15 to 18 degrees Celsius (°C) on high ground (the central Highveld plateau, which is 1,000 to 1,500 metres above sea level), to 25 °C in low altitude areas (northward from the central plateau towards the Zambezi River valley, and southward from the central plateau towards the Limpopo River). Total annual rainfall varies from below 500 millimetres (mm) in the Lowveld to between 750 to 1000 mm on the central Highveld plateau. The Eastern Highlands (the north-south mountain spine to the east of the country, where peaks are around 2,300 - 2,500 metres above sea level) are a bit colder and receive significantly more rain. The rainfall season spans the months October to April, with December, January and February being the peak rainfall months.

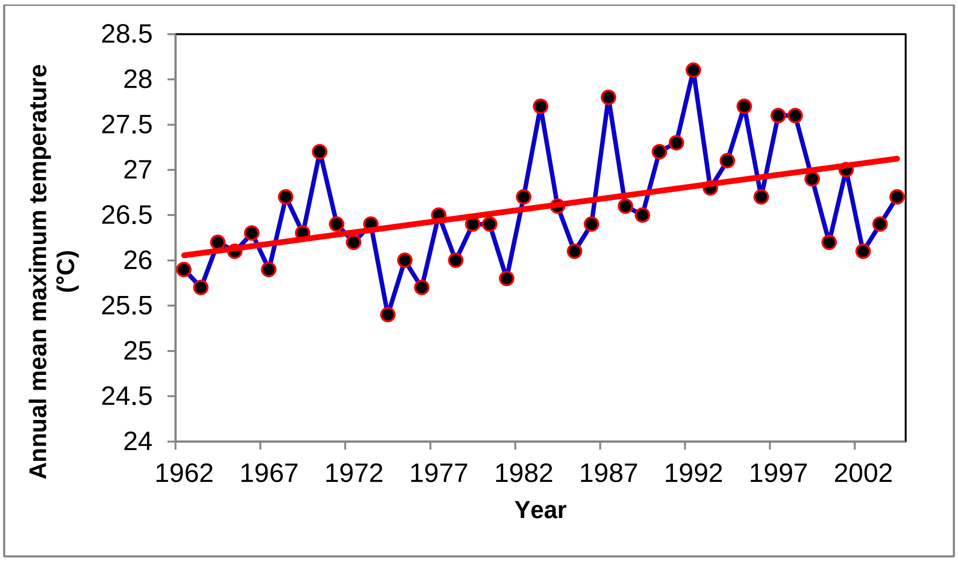
Based on analyses of minimum and maximum temperature trends, there is strong evidence that Zimbabwe has been experiencing a warming trend over the last few decades (Figures 3 and 4).

Figure 3. Annual mean minimum temperature trend, Zimbabwe (1962 - 2004)



Source: Zimbabwe Meteorological Services Department (2014)

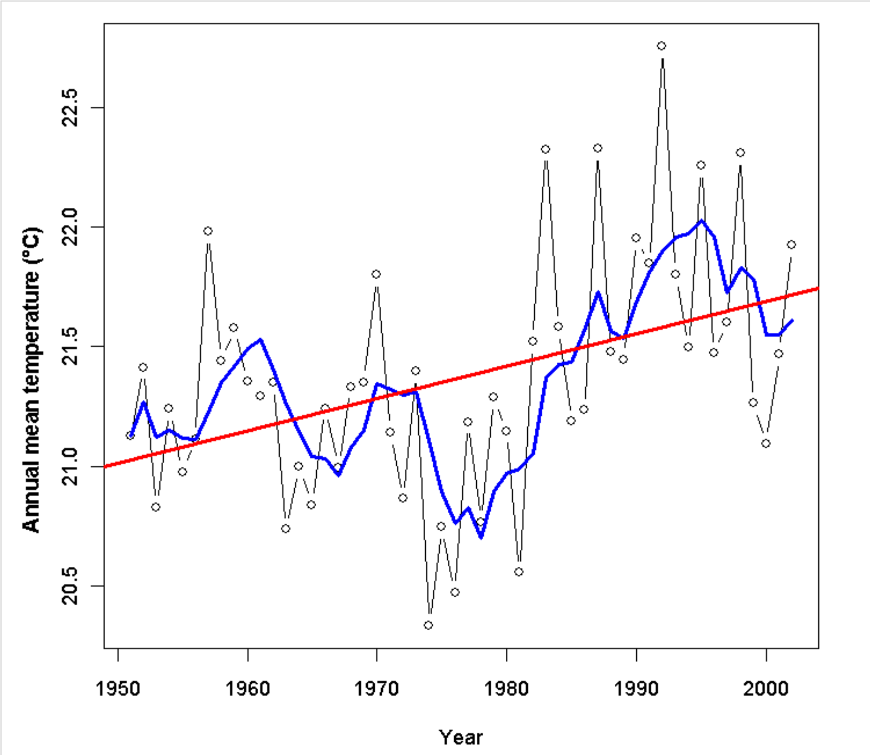
Figure 4. Annual mean maximum temperature trend, Zimbabwe (1962 - 2004)



Source: Zimbabwe Meteorological Services Department (2014)

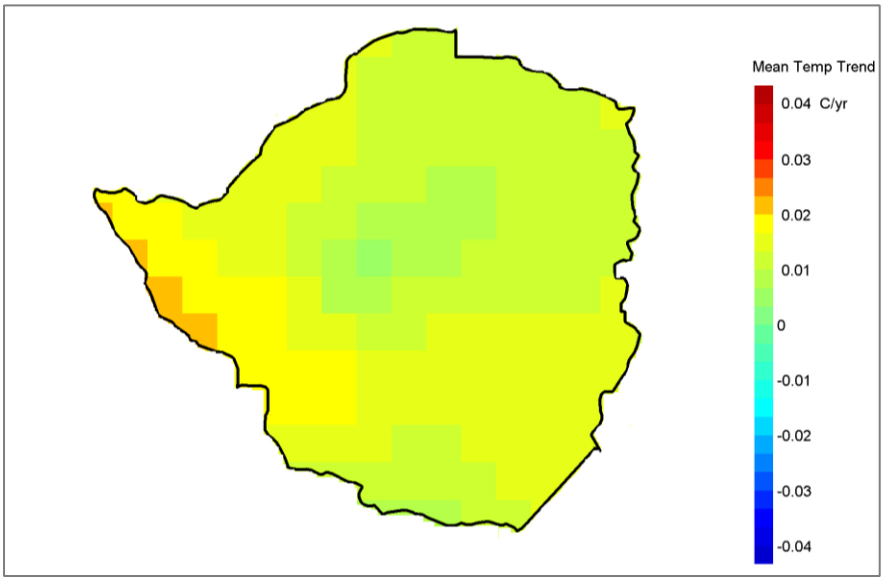
The annual mean temperature has increased by about 0.14 °C per decade (Figures 5 and 6). The warming trend is consistent with the global and regional trends of temperature rise in the past few years, and the timing of periods of most rapid warming has also been similar. The 1990s was the warmest decade of the past fifty years. The five warmest years on record in Zimbabwe have occurred since 1980, with the period 1983-1995 being the warmest.

Figure 5. Annual mean temperature trend, Zimbabwe (1951 - 2002)



Source: Climate Wizard

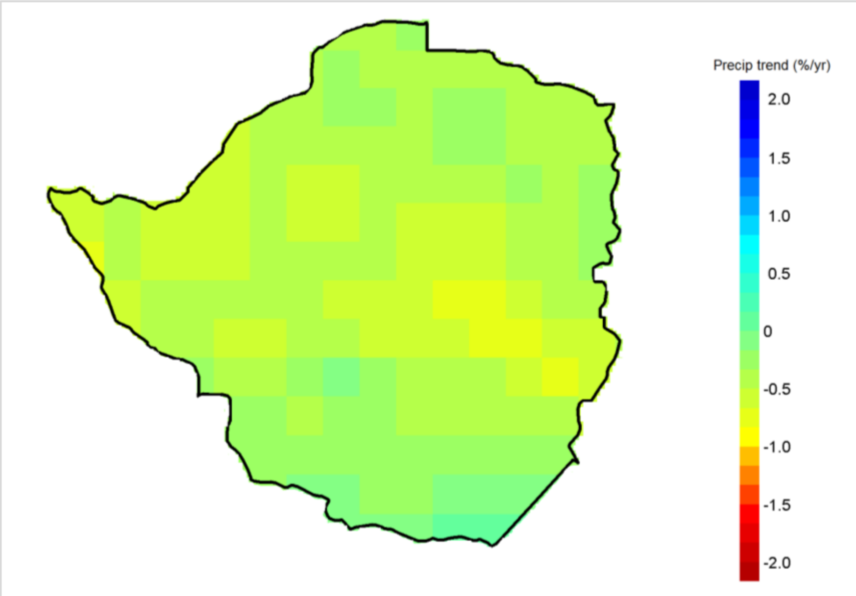
Figure 6. Annual mean temperature trend, Zimbabwe (1951 - 2002)



Source: Climate Wizard

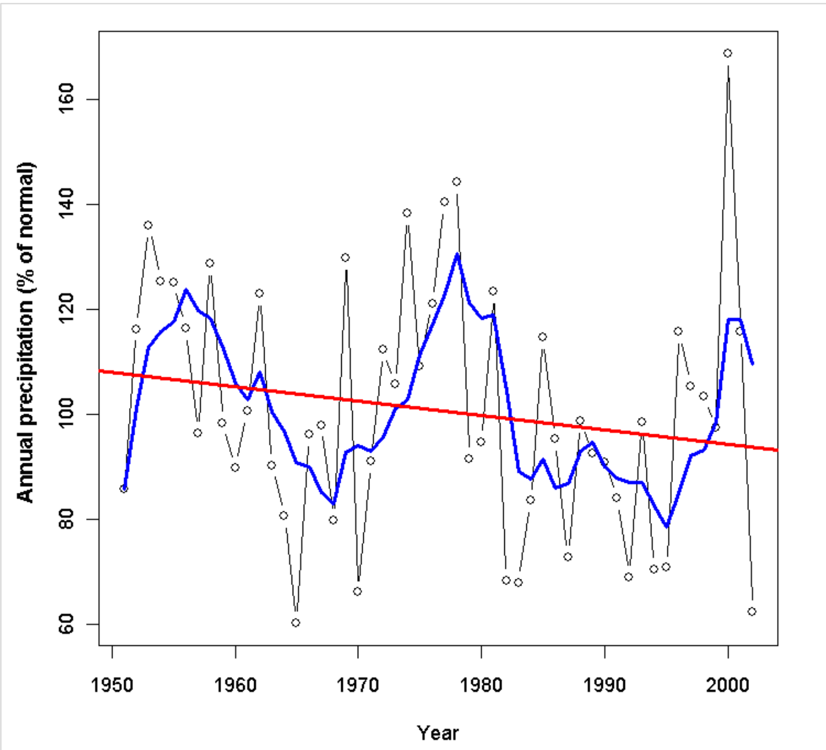
Analyses of the annual rainfall pattern and trend show that rainfall also experienced significant modifications during the same period, with the total amounts indicating a reduction at a rate of about 3% per decade (Figures 7 and 8). There has been an increased frequency of drought since 1980, with the five driest years occurring after 1980.

Figure 7. Precipitation trend, Zimbabwe (1951 - 2002)



Source: Climate Wizard

Figure 8. Annual precipitation trend, Zimbabwe (1951 - 2002)



Source: Climate Wizard

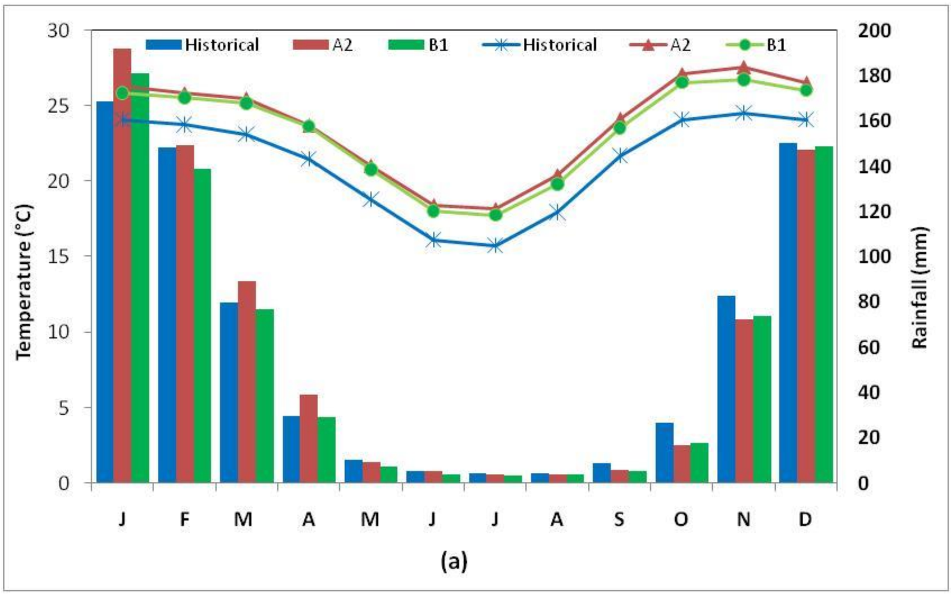
In 1998, the government of Zimbabwe outlined the changes in climate experienced in the country over the last fifty years, in a report prepared for the United Nations Framework Convention on Climate Change in 1998. These changes included increasing frequency and severity of droughts and floods, shifting rainfall patterns, and increasing intensity of mid-season dry spells (Government of Zimbabwe, 1998).

3.2 Future climate

The term 'future climate' is used to refer to projections of future temperature and precipitation regimes as given by the *ensemble average* or median prediction of the available 16 general circulation models (GCMs) used in the Coupled Model Intercomparison Project (CMIP5) (Taylor et al., 2012). Our future climate projections were based on the A2 and B1 Special Report on Emissions Scenarios (SRES) and the the IPCC's Fourth Assessment Report (AR4) (IPCC, 2000 and 2007). The A2 scenario is characterized by rising greenhouse gases (GHGs) associated with a growing, post-industrial economy and globalization, but mostly with low government intervention and high levels of competition. We herein refer to this scenario as the 'worst case scenario' (WCS). The B1 scenario, herein referred to as the 'best case scenario' (BCS), is characterized by falling GHGs associated with economic activity limited at an ecologically sustainable level and a high level of government intervention in the economy. All climate models consistently projected increased monthly ambient temperatures compared to the historical or baseline temperatures for both climate change scenarios (Figures 9a and b). The historical or baseline climate refers to the real or actual climatic conditions of the past, defined as the 1961 - 1990 period to match the World Meteorological Organization (WMO) standard. Climate projections exhibited the expected seasonal variations of temperature and precipitation in all locations. Although rainfall changes projected by the models were variable and uncertain, most of the models predicted that by the end of the 21st century, the average monthly rainfall for Zimbabwe would increase slightly during the summer cropping season (October to April). However, drier conditions are expected to persist from October to December, while the months of January to March may be slightly wetter than normal. The winter months (May to August) are projected to remain as dry as before. This would have the effect of reducing the length of the growing period in most locations.

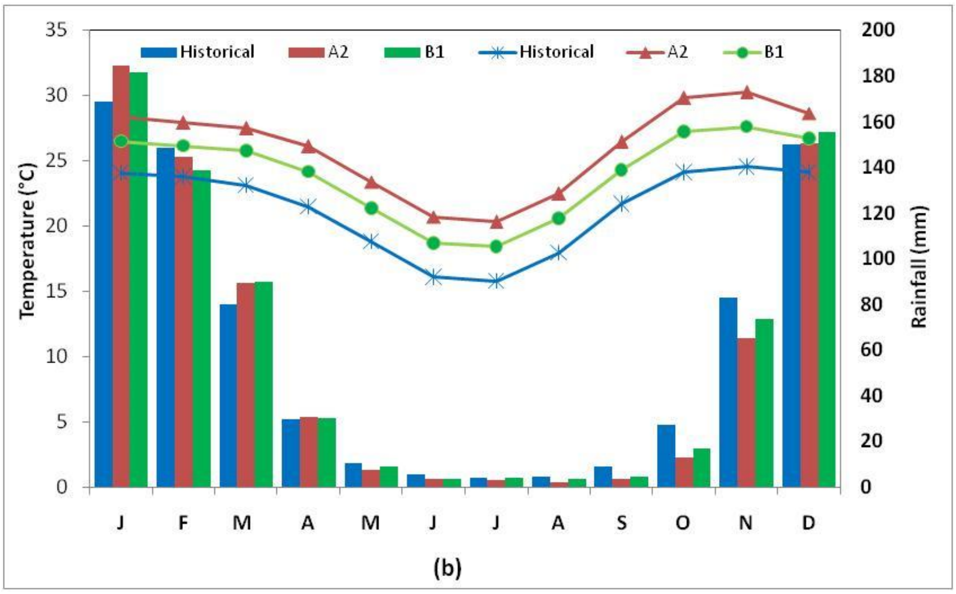
Figures 9a and 9b. Future climate of Zimbabwe in the 2050s and 2080s

Figure 9a. the 2050s



Source: Climate Wizard[3]

Figure 9b. the 2080s



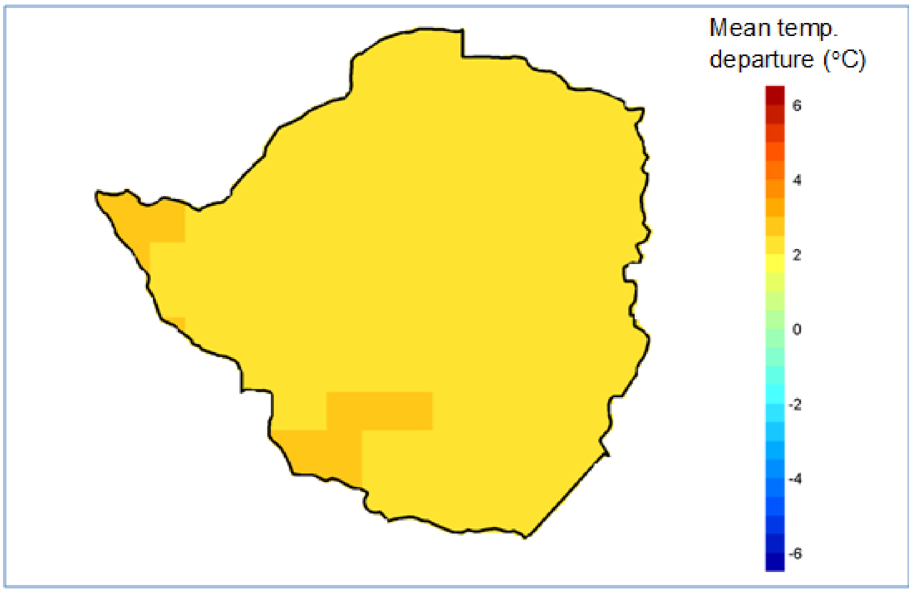
Source: Climate Wizard

[3] Figures 9 – 13 were developed using Climate Wizard, University of Washington and the Nature Conservancy; base climate projections downscaled by Maurer, Adam and Wood (2009).

Figures 10 - 13 depict the spatial distribution of the projected temperature and precipitation changes as departures (or anomalies) relative to the baseline period. A positive departure indicates an increase in the mean of the climate variable from the historic to the future period.

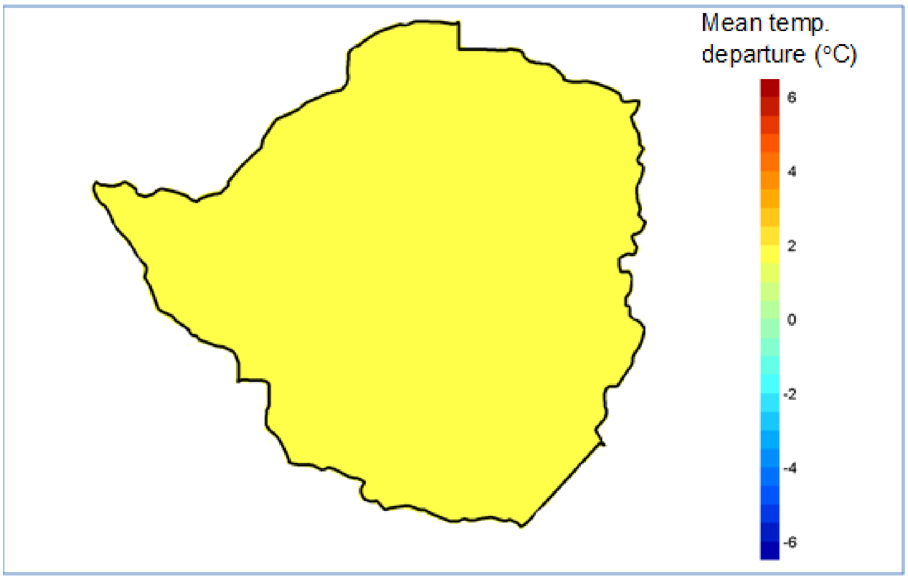
Figures 10a and 10b: Changes in mean annual temperature projected for the 2050s relative to the 1961 - 1990 period in Zimbabwe; the worst- and best-case scenarios

Figure 10a. The worst-case scenario



Source: Climate Wizard

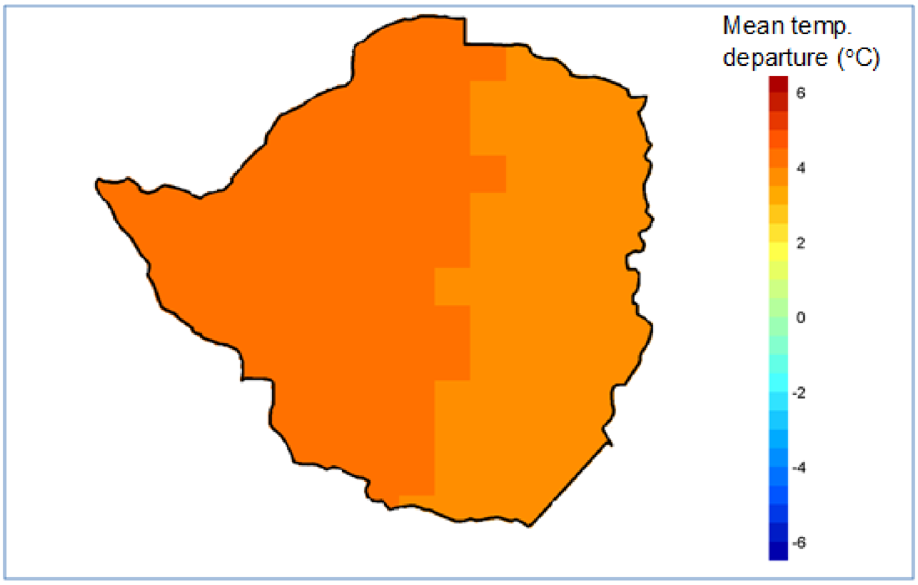
Figure 10b. The best-case scenario



Source: Climate Wizard

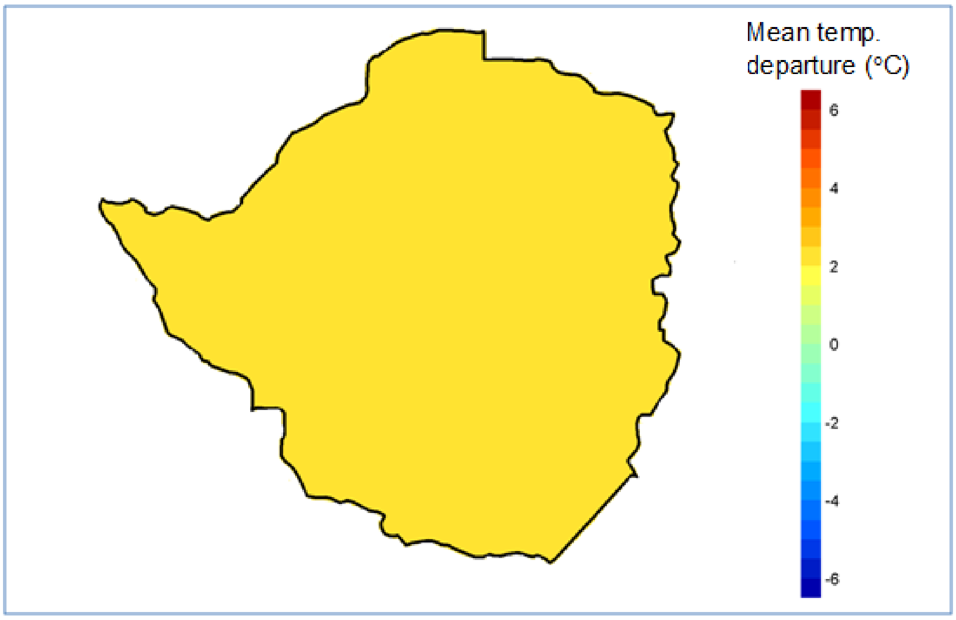
Figures 11a and 11b. Changes in mean annual temperature projected for the 2080s relative to the 1961 - 1990 period in Zimbabwe; the worst- and best-case scenarios.

Figure 11a. The worst-case scenario



Source: Climate Wizard

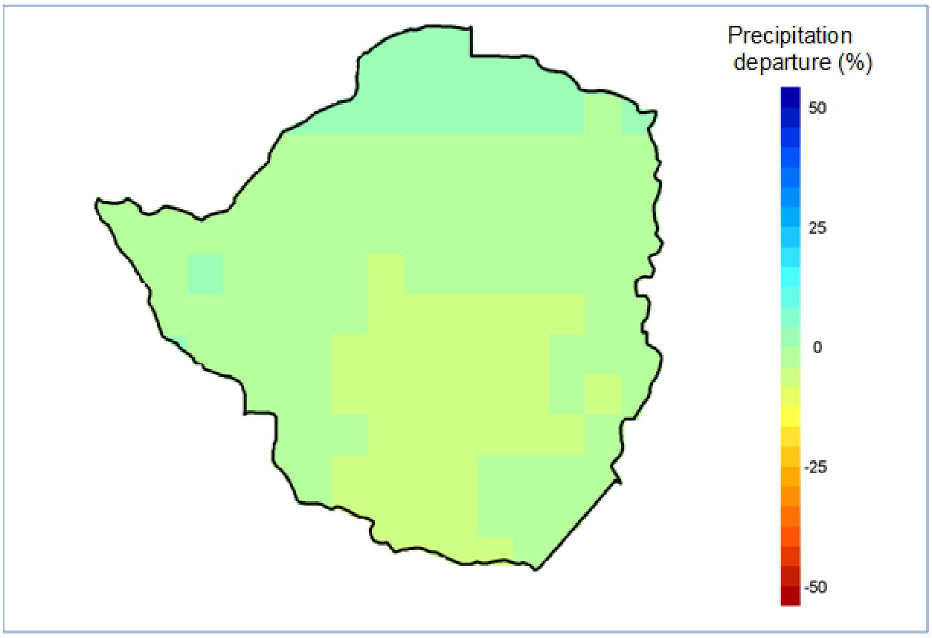
Figure 11b. The best-case scenario



Source: Climate Wizard

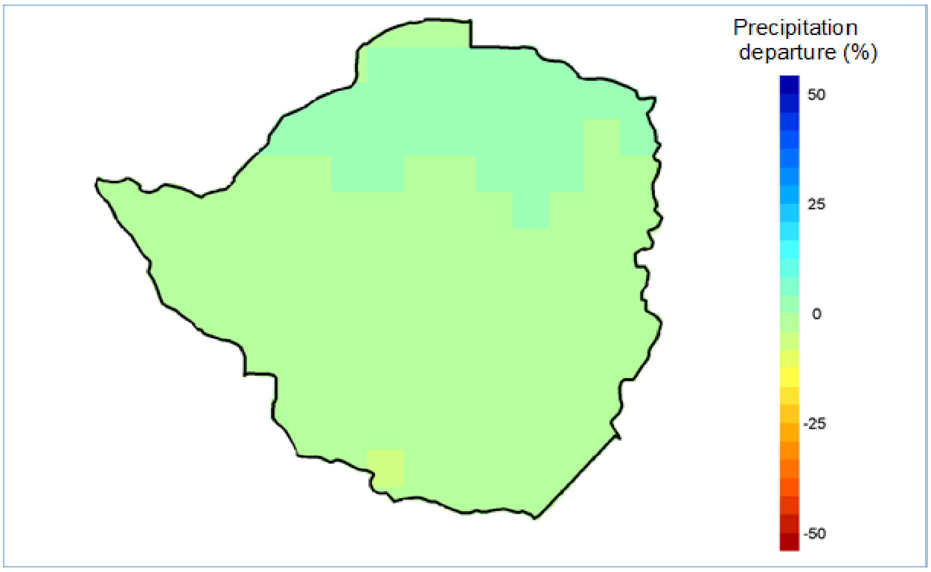
Figures 12a and 12b: Changes in annual precipitation projected for the 2050s relative to the 1961 - 1990 period in Zimbabwe; the worst- and best-case scenarios

Figure 12a. The worst-case scenario



Source: Climate Wizard

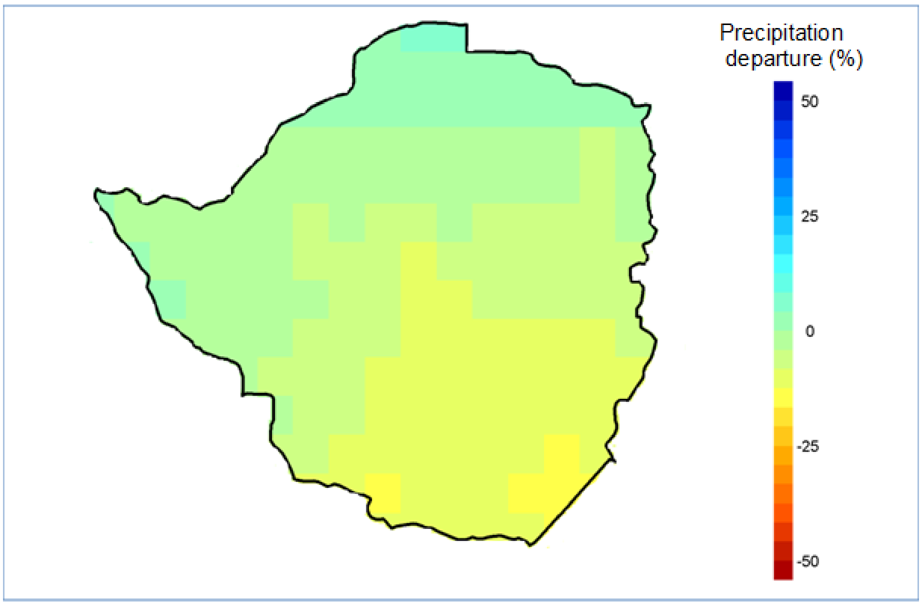
Figure 12b. The best-case scenario



Source: Climate Wizard

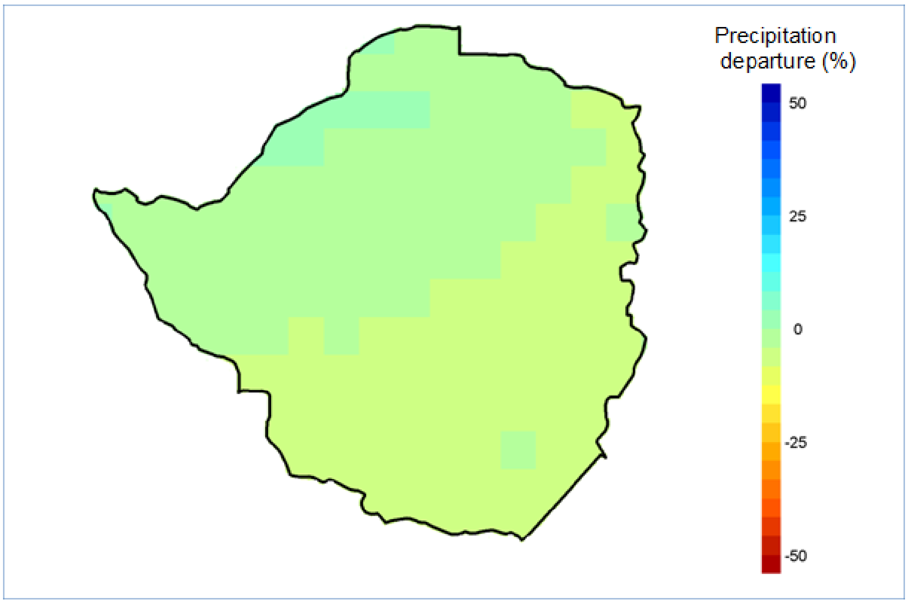
Figures 13a and 13b: Changes in annual precipitation projected for the 2080s relative to the 1961 - 1990 period in Zimbabwe for (a) the worst-case scenario and (b) the best-case scenario

Figure 13a. The worst-case scenario



Source: Climate Wizard

Figure 13b. The best-case scenario



Source: Climate Wizard

In the case of temperature, downscaled model simulations have consistently predicted a warming of between 1.8 °C above the baseline period (1961 - 1990) in the B1 scenario (the best-case scenario) and 2.6 °C above the baseline period in the A2 scenario (the worst-case scenario) across the country in the 2040 - 2069 period; and 2.6 to 4.8 °C above the baseline period for the 2070 - 2099 period under the B1 scenario and the A2 scenario, respectively (Table 1). In contrast, the projected changes in rainfall were small, within a 7% average, although varying considerably across GCMs and from one location to the other. Projected mean rainfall changes for Zimbabwe were a decline of 4.2% for the B1 scenario (best-case scenario) and an increase of +2.1% for the A2 scenario (the worst-case scenario) by the 2050s, and declines of 1.3% and 3.1% respectively by the 2080s. Projected mean evapotranspiration (ET_0) for Zimbabwe is expected to increase by between +5.7% (B1 scenario) and +6.0% (A2 scenario) by the 2050s, and between +7.6% (B1 scenario) and +12.6% (A2 scenario) by the 2080s (Table 1).

Table 1. Changes in temperature, precipitation and evapotranspiration projected for the middle and end of the 21st century in Zimbabwe based on outputs from the 16 GCMs

Scenario	**2040 - 2069 period**				**2070 - 2099 period**			
	T_{max} (°C)	T_{min} (°C)	Rainfall (%)	ET_0 (%)	T_{max} (°C)	T_{min} (°C)	Rainfall (%)	ET_0 (%)
Best-case scenario (B1)	+2.1	+1.9	-4.2	+5.7	2.7	2.6	-1.3	+7.6
Worst-case scenario (A2)	+2.4	+2.5	+2.1	+6.0	4.8	4.7	-3.1	+12.6

Source: Climate Wizard[4]

These results are in agreement with the changes in climate variables of significance to crops in southern Africa by the end of the 21st century projected by the IPCC, based on outputs from 21 GCMs (Solomon et al., 2007; Stocker et al., 2013) (Table 2).

[4] University of Washington and the Nature Conservancy. Base climate projections downscaled by Maurer, Adam and Wood (2009).

Table 2. Changes in climate variables of significance to crops in southern Africa projected for the end of the 21st century based on outputs from 21 GCMs

Month or period	Temperature change (°C)			Rainfall change (%)		
	Min	Mean	Max	Min	Mean	Max
Dec, Jan, Feb	1.8	3.1	3.4	-6	0	10
Mar, April, May	1.7	3.1	3.8	-25	0	12
June, July, Aug	1.9	3.4	3.6	-43	-23	-3
Sept, Oct, Nov	2.1	3.7	4.0	-43	-13	3
Annual	1.9	3.4	3.7	-12	-4	6

Source: IPCC (2007b and 2013)

3.3 Climate change impacts on crop production: past, present and future

Meteorological records demonstrate that Zimbabwe is already experiencing climate change, as evidenced by more variable rainfall, and more frequent and extreme weather events (including droughts, floods and tropical storms). The IPCC projections for sub-Saharan Africa suggest increased water stress, decreased yields from rain-fed agriculture, increased food insecurity and malnutrition, and the spread of arid and semi-arid land are all likely. These changing environmental conditions are expected to adversely affect several sectors in Zimbabwe, particularly agriculture. In this section, we present the simulated impacts of climate change on the major crops in Zimbabwe. Projected climate impacts according to crop type, calculated using the AquaCrop model, are shown in Table 3. The model was run with both historical and predicted future weather conditions in order to derive probabilistic projections of agricultural production impacts from climate change. Required model inputs included the climate (minimum and maximum temperature, precipitation and reference evapotranspiration), crop characteristics, planting dates, field management (fertility), and soil properties. The model was used to determine planting dates based on the criterion of the Department of Agricultural, Technical and Extension Services (AGRITEX) of the Ministry of Agriculture, Mechanization and Irrigation Development (MoAMID) of Zimbabwe, which is currently used by most farmers in Zimbabwe. According to this criterion, planting is advised as soon as the cumulative rainfall exceeds 25 mm during a maximum time span of seven days.

Table 3. Simulated climate impacts by crop type calculated using the AquaCrop crop-water productivity model

Crop	**1961 - 1990 period**	**2046 - 2065 period**		**2070 - 2099 period**	
	Simulated yields (tonne per hectare - t/ha)	*Yield change under B1 (best-case) scenario (%)*	*Yield change under A2 (worst-case) scenario (%)*	*Yield change under B1 (best-case) scenario (%)*	*Yield change under A2 (worst-case) scenario (%)*
Maize	6.02	-23.1	-24.3	-24.7	-38.4
Sorghum	3.04	-10.3	-10.6	-8.7	-17.9
Millet	2.61	-9.5	-11.1	-11.6	-18.6
Groundnut	1.54	-4.4	-7.6	-8.1	-11.6

Source: AquaCrop

The model predicted historical planting dates ranging from 7 to 14 November. The simulated yields for all crops ranged from 1.5 to 6 t/ha and were higher than the average yields expected under smallholder production systems in Zimbabwe. Maize yields are typically around 1 - 2 t/ha on smallholder farmers' fields in marginal regions like the Lowveld (Phillips et al., 2002), and 4 - 8 t/ha on average for the remainder of Zimbabwe (SeedCo, 2005), while all other crops typically average less than 1 t/ha. Possible causes for such differences were that the model did not consider farmers' management practices, the wide variations in soil types and climate across the country, and the low fertility levels characteristic of smallholder farmers' fields. Nonetheless, the results are still useful as we were only interested in yield changes due to climate change and not the absolute values of yields. The AquaCrop model simulations predicted that climate change will shift planting dates towards delayed planting by around one week in the period 2046 - 2065 and two to three weeks in the period 2046 - 2065. Overall, mean yield reductions were identified for all four crops. The most significant yield reduction projected within the 21st century was for maize (28%), while the other crops were predicted to have lower yield reductions: sorghum (13%), millet (12%) and groundnut (8%). Maize yield reductions were found to be significant for both mid 21st century and end of the century, while for the other crops only the projected changes for the 2080s were significant.

These results are consistent with the results of other researchers who have also projected reductions in crop yields due to climate change in most southern African countries within the 21st century. For example, Jones and Thornton (2003) predicted that maize yields under small-scale rain-fed production in most southern African countries will likely decline by an average of 10% by mid-century, while Thornton et al. (2011) concluded that the projected 4 - 5 °C of future warming will result in reductions in maize and bean production in southern Africa of 16% and 68% respectively by the end of the 21st century. Other researchers estimated mean yield declines of 5 - 30% for maize (Burke, Lobell and Guarino, 2009; Fischer et al., 2005; Jones et al., 2003; Lobell and Burke, 2010; Lobell et al., 2008; Masanganise et al., 2012; Thornton et al., 2009, 2011; Walker and Shulze, 2006); 15 - 30% for sorghum (Schlenker and Lobell, 2010; Chipanshi, Chanda and Totolo, 2003); 10% for millet (Knox et al., 2012); 15% for groundnut (Schlenker and Lobell, 2010); and 18% for wheat (Liu et al., 2008), in southern Africa by the end of the 21st century.

4. PROGRAMMES ON CLIMATE-RESILIENT SEED SYSTEMS

4.1. CGIAR Research Program on MAIZE

Maize is Zimbabwe's staple food crop, with the annual maize grain requirement of the country standing at 1.8 million tonnes (Mudzonga and Chigwada, 2009). It is therefore the most widely grown crop in the country, accounting for 80% of the country's total cereal production. Maize is produced by large-scale and small-scale commercial and communal farmers. The majority of maize producers are small-scale and communal farmers, cultivating 0.5 - 3 hectares of land with variable yields averaging 1 - 1.5 t/ha (Bänziger and Cooper, 2001). In Zimbabwe, only 5% of maize is produced commercially where yields as high as 10 - 14 t/ha have been reported. Major constraints to the production of maize in the country include drought, pests and diseases, labour shortage, and the high cost and lack of availability of seed and fertilizers.

Intensive and proactive efforts are needed to sustain and enhance maize yields and economic returns in the face of ever-evolving and often location-/region-specific biotic and abiotic stresses, accentuated mainly by climate change. Maize is largely (about 80%) grown as a rain-fed crop in sub-Saharan Africa, Asia and Latin America, and is particularly vulnerable to an array of abiotic and biotic stresses; consequently, yields are usually less than half of those under irrigated systems, which is the main focus of private sector investment (Shiferaw et al., 2011).

The CGIAR Research Program (CRP) on MAIZE, led by CIMMYT in partnership with the International Institute of Tropical Agriculture (IITA), has been successful in developing and deploying an array of climate-resilient and nutritionally enriched maize hybrids/synthetics in sub-Saharan Africa, Asia and Latin America, through various projects. Those projects of relevance to Zimbabwe are:

- DTMA: Drought-Tolerant Maize for Africa (Angola, Benin, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, Zimbabwe)
- IMAS: Improved Maize for African Soils (Kenya, South Africa, Zimbabwe)

- Maize HarvestPlus, in collaboration with the CGIAR programme on agriculture for nutrition and health (A4NH): Biofortification of tropical maize to combat micronutrient malnutrition (high pro-vitamin A and high Zn; Benin Republic, Democratic Republic of the Congo, Ghana, Mali, Nigeria, Zambia, Zimbabwe, Malawi, Nicaragua, Guatemala, Mexico, Colombia and Brazil).

In Zimbabwe, the main thrust of the projects was developing farmer-selected maize varieties with increased productivity under the stress-prone conditions, and strengthening stakeholders in the maize seed sector to work towards a more diverse and more stable seed industry that is responsive to the needs of resource-poor farmers. A publication entitled 'Understanding Zimbabwe maize seed legislation' (Kadzere and Karadzandima, 2007) was developed as a way of sensitizing the regulatory environment and variety release system to the Zimbabwean seed sector, and more than 500 copies were distributed to stakeholders in the seed sector. The projects have contributed to the release of six drought-tolerant (DT) hybrids and three DT open-pollinated varieties (OPVs) through the Ministry of Agriculture, Mechanization and Irrigation Development's Crop Breeding Institute (CBI), and were contracted to nine private seed companies for seed multiplication, resulting in a cumulative estimated contribution to seed volumes of more than 136,602 tonnes of certified seed to date. Private seed companies in Zimbabwe have released eleven hybrids and two OPVs for commercial seed production. The availability of released varieties and their commercial seed production is pivotal to improving seed security of resource-poor farmers.

Through the DTMA project alone, nearly 180 unique drought-tolerant maize variety releases were made across sub-Saharan Africa, with significant impact (Fischer et al., 2015). In 2014, nearly 52,000 tonnes of certified seed of diverse DT maize varieties were produced and made available to the farmers by the seed companies and community-based seed producers. In recognition of such successes, the 2015 CGIAR Independent Evaluation Arrangement (IEA) team report on MAIZE noted that the 'Research design and approaches are innovative and sometimes state-of-the-art. Processes and partnerships are designed to ensure that latest scientific thinking is reflected in methodology and analysis. Internal processes to assure science quality appear to be robust. The publication record is excellent, with ten CRP scientists having H-factors greater than 15, which is good in this area of science' (CGIAR-IEA, 2015, p. 44).

4.2 Coping with Drought and Climate Change project

Coping with Drought and Climate Change (Zimbabwe CwDCC) was an initiative of the Government of Zimbabwe and the United Nations Development Programme (UNDP), through its Global Environment

Facility (GEF)[5]. The project worked with smallholder farmers in Chiredzi district to demonstrate diversification of crop types, soil moisture management and the use of climate information in drought risk management and climate change adaptation. The component of Zimbabwe CwDCC on crop production focused on working with farmers to promote the use of different crop types and soil moisture management as climate change adaptive strategies. Demonstration plots were established in four sites across Matibi II communal lands of Chiredzi district. Interventions under this initiative focused on diversifying the crop mix to include open-pollinated, drought-tolerant maize varieties, as well as sorghum, pearl millet, groundnut, cowpea and cassava. These crops were integrated with soil moisture management practices and the identification of appropriate planting dates. Sensitivity analysis on crops shows that Chiredzi is becoming unsuitable for maize, sorghum and cotton production under the worst climate change scenario, where temperatures rise by up to 5 °C and rainfall declines by about 50% by 2050. The best-case scenario shows the whole district remaining suitable for the production of the three crops, namely maize, sorghum and cotton. Community participatory approaches were used to identify possible priority adaptation measures using the procedure of root cause analysis as a framework to identify risk reduction measures. Priority adaptation measures identified for Chiredzi district included:

- Establishing village seed banks with seed of traditional and improved drought-resistant crops/varieties.
- Establishing field schools for farmers.
- Improving soil fertility and moisture management.
- Ensuring that appropriate crop seed is in place before the rains.
- Promoting mulching practices so that the limited soil moisture available is saved during critical stages of crop growth.
- Supporting irrigation development.
- Reducing human - wildlife conflicts.

4.3 Ongoing projects at ICRISAT Zimbabwe

Several ongoing projects, coordinated by ICRISAT in Zimbabwe, aim to address climate variability, and develop farming systems and production strategies that are able to withstand the climatic vagaries of the semi-arid tropics. The multidisciplinary approach followed incorporates various scientific disciplines and strategies to reduce risk and equip small-scale farmers with the tools to cope with high climatic stochasticity. Central to the work of the projects is the combined use of

[5] See http://adaptation-undp.org/projects/sccf-cwdcc-zimbabwe, accessed 26 March 2017.

climate information and appropriate improved crop and livestock systems, designed and backed up by biophysical and economic modelling and on-farm testing.

These ICRISAT projects are generally at inception level and have not had any measurable impact to date. However, they are worth mentioning as they relate to their proposed contribution to climate change. Below is a summary of the said projects and their perceived contributions, developed from the ICRISAT Zimbabwe Country Strategy Draft Report that was prepared in October 2016.

4.3.1 Building Farmers' Resilience to Production Variability through Enhanced Climate Services and Improved Agricultural Technologies in Semi-Arid Regions of Zimbabwe[6]

This project seeks to enable farmers to make informed decisions with due consideration to historical and current climate information, including seasonal climate forecast information, in selecting crops, varieties and management practices. It aims to expand the concept of agricultural extension beyond simply the use of productive inputs such as fertilizers, seed and better technologies; it also strives to make sure that agricultural extension also includes the use of information-based inputs, such as climate forecasts, which may serve to reduce risks at farm level. This could help decision makers reach better farm-management decisions and prepare themselves for more effective adaptation to climate variability. The project realizes that enhanced communication of climate-related information is an option that could assist in adaptation strategies and timely decision-making by farmers. Currently, government extension staff are tasked with providing information to farmers, but services are stretched with low numbers of staff and poor national coverage. Therefore, scaling-up the use of weather-related information, including seasonal climate forecasts, through a participatory manner alone would not be feasible due to manpower shortages, as well as owing to the fact that rural communities are geographically isolated. Consequently, the project has introduced cheaper and more manageable means of scaling-up the use of information and communication technologies (ICTs), in this case through short message services (SMS) via mobile phones.

The project is also working on enhancing the capacity of AGRITEX and lead farmers to access and understand both seasonal climate forecasting (SCF) and 'weather-within-climate' information in semi-arid Zimbabwe, for improved decision-making in farm management. It combines the use of climate information with agricultural technologies through climate field schools (CFS), a modification of the farmer field school approach. The project hypothesizes that since rainfall within season is one of the major problems, and the amount of rainfall cannot be influenced, then technologies that enhance water-use efficiency are one of the major areas of research that should be integrated into

[6] This section was based on data from the ICRISAT Zimbabwe Country Strategy Draft Report, October 2016 (unpublished).

the existing strategies for farmers in semi-arid lands to cope with climate variability and ultimately adapt to climate change. Through the climate field schools, the project is promoting the adoption of production systems and management practices that can withstand climate-induced stresses and lead to sustainable intensification. ICRISAT's work has shown that enhancing smallholder farmer's access to improved drought-tolerant crop varieties, such as sorghum and pearl millet, is a critical step for increasing agricultural productivity and resilience. Supporting alternative soil fertility options, including demonstrating the multiple benefits of rotating and intercropping small grains and legumes in semi-arid farming systems, is one of the key activities of the project.

At present, the project has no private sector engagement and it proposes to partner with Econet, a major telecommunication service provider, to reach out to a larger community. Project work is being implemented in collaboration with the Meteorological Services Department of Zimbabwe (MSDZIM), providing forecasts (and weather updates) to the farmers and AGRITEX, assisting farmers with the interpretation of the weather and seasonal climate forecasts, and giving technical advice.

The initial part of this project was implemented in Hwange district, with key achievements of the 2014 - 2015 season including[7]:

- A total of 32 AGRITEX personnel (~60% female) from Hwange district in Zimbabwe were trained to transfer knowledge and skills relating to (i) practical implications of climate variability (and change); and (ii) appropriate coping and adaptation strategies for smallholder farmers. The extension personnel were also trained to access/understand both SCF and 'weather-within-climate' information for improved decision-making in farm management.
- A further 15 lead/contact farmers and ~500 farmers were trained over the 2014 - 2015 season by AGRITEX, who accessed the SCF and weather updates through short message services (SMS) via mobile phones. Fifteen (15) climate field schools (CFS) that integrated various climate-smart agricultural technologies (including conservation agriculture (both mechanized and basin), micro-dosing, intercropping, and diversification) were established in 2014 - 2015 season, and these have reached out to more 500 farmers.
- Fifteen climate field schools (CFSs) were established in three wards of Hwange district in Zimbabwe. Each ward had five contact farmers and five demonstration sites. At each CFS, a contact/lead farmer was chosen by the farmers (with assistance from the extension workers) and this farmer had about 20-30 farmers working with him/her,

[7] This section was based on data from ICRISAT (2015).

learning from the demonstration plot); hence the project reached out to about 500 - 1,000 farming households in Hwange district.

- Participatory SCF dissemination workshops were held with the 15 CFSs. Weather-related information was sent to the contact farmers and the extension workers, and once they had received these (every ten days), they met up at the demonstration plot, and discussed the appropriate crop and farm management strategies, taking into account the forecast.
- The project also aimed at introducing good quality seed through a communal seed multiplication venture. ICRISAT provided seed to a total of 30 farmers who were involved in multiplying small grain (sorghum variety Macia, and pearl millet variety Okashana 1). This seed was then bulked (3.5 tonnes of Macia sorghum seed and 2 tonnes of Okashana I pearl millet seed was produced from the multiplication process in 2014 - 2015) and will be distributed locally for the 2015/16 season, so that there is quality seed available for more farmers in the district. Thus, the project aimed to reach about 750 - 1,000 farmers in Hwange district for the 2015/16 season.

4.3.2 The Livelihoods and Food Security Programme

The Zimbabwe Livelihoods and Food Security Programme (LFSP) is being implemented in Mutare, Makoni and Mutasa districts of Manicaland province; Kwekwe, Gokwe South and Shurugwi districts in Midlands province; and two districts, Guruve and Mt Darwin, in Mashonaland Central province. The programme will target 126,975 smallholder farm households in these areas and is expected to reduce food insecurity for 348,975 people.

This four-year programme is being implemented through two main components:

- An Agricultural Productivity and Nutrition (APN) component, which is managed by the Food and Agriculture Organization of the United Nations (FAO) with the objective of increasing smallholder farm productivity by introducing improved and climate appropriate agricultural practices, enhancing access to finance and markets, and promoting the production and consumption of safer and more nutritious foods.
- A Market Development (MD) component, which is managed by Palladium, with the objective of linking smallholder farmers to profitable commercial markets, and stimulating the demand and supply of affordable nutritious foods.

ICRISAT's role in this programme is to identify viable value chains that can be pursued to contribute to food security, household nutrition and access to markets. Increased access to input and output markets, supporting the production of lucrative and nutritious crops, will increase the sustainable production and income from these crops while addressing food security and household nutritional needs.

Smallholder farmers within the different target areas are included, many of whom are women. The project works with a wide spectrum of stakeholders: farmers, local governments, institutions and community-based organizations (CBOs), the private sector and various partners on the ground.

The programme has a specific objective to include women farmers as major stakeholders/beneficiaries. An innovation platform ensures participation by all stakeholders. Private sector engagement in this platform is strong, and many local input suppliers, most of which are agro-dealers, are keen to participate.

The work is being implemented through multiple CRPs, including Dryland Systems; Grain Legumes; Dryland Cereals; and Climate Change, Agriculture and Food Security (CCAFS). Although the programme has a very clear value chain focus, using innovation platforms to identify gaps and opportunities in the production to market system, these are not clearly specified in the programme documents. The gaps are addressed through the innovation platform processes.

4.3.3 Rainwater Harvesting to Sustain Crop Growth in Dry Spells

Irrigation may be the most obvious response to droughts and lengthy mid-season dry spells under rain-fed agriculture, but it is generally expensive and requires technical know-how, making it unreachable for most smallholder farmers. Rainwater harvesting, which involves inducing, collecting, storing and conserving run-off water for agriculture (including livestock), offers the possibility of improving water supply. The project aims to identify rainwater harvesting methods that are suitable for the different localities, so as to improve crop growth and bridge the mid-season dry spells. The implementation of rainwater-harvesting systems is influenced by biophysical, hydrological and socio-economic challenges. This project seeks to take these into consideration when researching best rainwater-harvesting methods for different situations.

4.3.4 Re-designing Smallholder Crop-livestock Systems in Semi-arid Southern Africa to Address Poverty and Enhance Resilience to Climate Change: Stakeholder-driven Integrated Multi-modelling Research

This project engages stakeholders and uses the integrated assessment approach to create pathways to sustainable futures for smallholder crop-livestock systems in semi-arid southern Africa. For Zimbabwe, the stakeholders include ICRISAT, the University of Zimbabwe, the Institute of

Development Studies at the National University of Science and Technology (IDS-NUST), Matopos Research Institute and AGRITEX, representing the government; and development partners and private sector players. The target beneficiaries are smallholder farmers in Nkayi district in Zimbabwe; 60% of farm households in Nkayi will be exposed to greater vulnerability by 2050 due to climate change. Computer simulated on-farm future scenarios and solutions serve in guiding policymakers. Preliminary results on the impacts of sustainable intensification options in Nkayi district revealed that farmers in the district are already vulnerable to the consequences of climate hazards. Climate change would worsen the situations of about two thirds of the population. Options for sustainable intensification would offset impacts of climate change for more than three quarters of the population. Drastic interventions will improve livelihoods and lift more than half the population out of poverty (ICRISAT, 2016).

Adaptation packages designed for Nkayi district initially targeted 160 households (HHs), 43% of which were considered very poor, with a farm size of 1.3 ha, and no cattle; 38% were identified as being poor/medium, with 1.8 ha of land, and up to eight cattle; and 19% were deemed better off, with farm sizes of 2.5 ha and over, and more than eight cattle. The key features of the packages were based on:

- Crop diversification, incorporating less maize and more groundnut, for better soil fertility, family nutrition and income; drought-tolerant sorghum for 'very poor' households; dual purpose forage *Mucuna pruriens,* to support livestock and improve soil fertility; and other crops such as common beans (for very poor households) and bana grass (for better-off households).
- Fertilizer micro-dosing for increased yields.
- Livestock with more cattle and small ruminants for generating income.
- Milk production enhanced by protein-rich fodder from *mucuna* and groundnut haulms, which increases milk yield.

For incentivizing farmers to adopt the adaptation package, large-scale measures need to be taken by policymakers and key stakeholders for linking farmers to markets and integrating crop and livestock production. The impact of drastic adaptation packages on net returns was evaluated, suggesting that 'very poor' households will double their returns; the 'poor' and 'better-off' households will gain an increase of 50% – 75% in household income, while the entire community will see an 86% increase on net returns as compared to 72% for incremental technologies (ICRISAT, 2016).

This project will generate information on cropping systems, technologies and market opportunities adapted to the changing climatic context in the drier parts of the country, and information that policymakers can use for decision making. The development of the AgMIP tool 'Impacts Explorer' will make information available to a wide range of users, enhancing the use of research information by decision makers. Stakeholders will benefit from co-learning in climate change adaptation processes, accessing this new capacity development tool. Research institutions provide additional information on climate change, as well as capacity development, to stakeholders, including government, development practitioners and the private sector, at regional and national levels, as users of the Impact Explorer tool. Details of activities implemented will inform the consultative processes of countries on climate policy[8].

4.3.5 Zimbabwe Crop-Livestock Integration for Food Security

The Zimbabwe Crop-Livestock Integration for Food Security (ZimCLIFFS) project explores ways to increase agricultural production in smallholder farming systems through better-integrated crop and livestock production and market participation. It promotes a participatory technology development approach, engaging multi-stakeholders to improve access to technologies, resources and markets to ensure quick-win benefits, and fast and wider scaling out. The project aims to increase knowledge and skills through enhanced understanding of household dynamics, integrated farming systems based on robust farm models, and strengthened capacity in multi-stakeholder processes.

Through innovation platforms, the project identifies high potential value chains in context and engages the different actors, including women and men farmers, value chain actors (e.g. agro-dealers, and local retailers engaged in the supply of fertilizers, veterinary medicines and feedstuffs), local government, development agencies and researchers (national and international).

The project impacts on food security and rural livelihoods through more integrated farming systems, with crop and livestock technologies that sustain more diversified and intensified farming. It enhances co-learning through multi-stakeholder engagement and knowledge brokerage, joint testing and scaling out of relevant technologies. It contributes to environmental impacts from increased biomass and forage production, and the more productive use of crops and livestock.

The private sector (agro-dealers, seed houses, traders, abattoirs) will better understand business opportunities at input and output markets, incentives arising from increased demand for inputs and services, and turnover of higher quality and value-added agricultural products.

The project responds to national priorities to reduce chronic food insecurity and donor dependence, and alleviate poverty through better-integrated farming systems, innovations and equitable

[8] For further details on Impacts Explorer, see http://www.agmip.org/blog/2016/10/11/impacts-explorer/, accessed 14 January 2017.

participation in markets and technology development. It is well aligned with the Inclusive Market-Oriented Development (IMOD) strategy of ICRISAT; for example, the rediscovery of groundnut as a crop for food, feed and cash income, has led to a new partnership between ICRISAT and the government of Zimbabwe. Furthermore, the project provides information on entry points for crop livestock intensification in the Chinyanja Triangle Action site, as part of the Drylands System CRP.

4.3.6 Enhancing Nutrition, Stepping-up Resilience and Enterprise

Enhancing Nutrition, Stepping-up Resilience and Enterprise (ENSURE) is a multi-million-dollar project within which ICRISAT plays a relatively small technical support role. However, our role is crucial in developing more resilient and market orientated crop-livestock systems. The aim is to develop functional systems for cultivating cereals and legumes, and raising livestock. The project also seeks to enhance the marketing of livestock and groundnut to improve income generation options for the smallholder farmers, with groundnut and livestock (cattle and goats) being the main commodities marketed. The system improvements will entail greater integration of the crops and livestock within the system, as well as within markets. The project works with a wide spectrum of stakeholders: farmers, local government institutions and CBOs, the private sector and various partners on the ground.

The ENSURE project has specific objectives concerning gender. The ICRISAT component will focus on goats and groundnut, both of which are strongly associated with women farmers. Access to markets will increase income while the increased production of both these highly nutritious commodities will enhance household nutrition. Income from these commodities will also fund education and human health. In addition, increased production of feed and fodder will reduce pressure on rangelands.

The ENSURE project focuses on groundnut, but includes sorghum and has a strong IMOD approach. The main risk from ICRISAT's point of view is that other project partners may fail in achieving their goals and/or may be less efficient in their work. Project work primarily fits into two CRPs: Dryland Systems and Grain Legumes. No real gaps have been identified, as various organizations are involved with value chain work.

4.3.7 Strengthening Groundnut Value Chain to Develop Resilient and Profitable Rural Livelihood Systems

Groundnut represents better nutrition and soil fertility, and has great potential as a cash crop in Zimbabwe. As in most countries in sub-Saharan Africa, groundnut is considered a women's crop and has received limited support for improving production technologies or developing policies that support access to high value markets. Production of groundnut in Zimbabwe has been declining in recent years owing to a myriad of factors. Production gains have been hampered by limited (or lack of) access to improved seed varieties, poor agronomic practices in groundnut farming, and inadequate market access. In addition, aflatoxin contamination has been high, and has continued unmonitored in many cases due to lack of awareness among the stakeholders, particularly smallholder farmers and small-scale traders and processors. Both producers and processors have limited access to information on commodity access and quality, and this is hindered by a lack of clear-cut policies on the groundnut value chain. Such challenges in the groundnut sub-sector, have led to traders and industry opting for the grain imports from neighbouring countries.

ICRISAT draws on the experiences of Malawi, and East Africa in general, for improving the groundnut value chain. The starting point is to deal with the supply side. The adoption of improved groundnut varieties, fertilizers and agro-chemicals leads to productivity gains, thereby increasing the supply of the crop to the market. Diverse groundnut varieties are required for different agro-ecological and market needs. Ramping-up production by strengthening seed systems will improve access to new varieties, and unlock the opportunity for diverse value chain actors in the economy, inclusive of farmers. There is also a need to fast track the release of locally adapted improved groundnut varieties in Zimbabwe. These varieties have already been developed by ICRISAT – Malawi, and are being tested for release in Zimbabwe through a partnership with the Department of Research and Specialist Services (DRSS) of the MoAMID. Equally important is the need to intensify production using sound agronomic practices that improve soil fertility and prevent degradation while increasing productivity.

Aflatoxin contamination must be controlled. Detection methods commonly used in developing countries are expensive, complex and time consuming for the majority of smallholder groundnut producers. In Malawi, ICRISAT supported the National Smallholder Farmers' Association of Malawi (NASFAM) to set-up small laboratories for members to use, where samples are brought from farms for testing at a cost of one US dollar (US$) per sample - compared to the previous US$25 per sample test. This new system that can be used in remote farms could be adapted to the Zimbabwe set-up to facilitate early detection of aflatoxin contamination and the development of control strategies. The testing of aflatoxin will differentiate products for various markets, and will also attract higher value markets such as larger groundnut processors and even export markets.

The following activities are planned for this project:

- Conduct a groundnut value chain analysis.
- Partner with DRSS to test and fast track the release of improved varieties of groundnut developed by ICRISAT through its breeding programmes.

- Strengthen groundnut producer groups through, for example, the formation of a groundnut farmers' association.
- Build the capacity of production groups to monitor quality and be able to grade groundnut.

4.3.8 Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through On-Farm Monitoring, Adaptive Management and Agricultural Innovation Platforms

Using innovation platforms, this project analyses the challenges and market opportunities of existing small-scale irrigation systems to increase the overall efficiency of households. Linking crop production with market opportunities, and integrating crops with livestock, offers unrecognized synergies.

The project connects farmers to markets that would allow them to grow profitable crops, and this will increase the functioning of irrigation systems, as well as household nutrition and income. This will improve productivity of some irrigation schemes that had been underutilized, making a larger contribution to food and nutritional security. Beneficiaries of this project are the smallholder farmers with plots in different irrigation schemes, many of whom are women. The project works with a wide spectrum of stakeholders: farmers, local governments, institutions and CBOs, the private sector and various partners on the ground. Innovation platforms have ensured multi-stakeholder participation.

The project works directly with farmers in the different irrigation systems, inclusive of all stakeholders, increasing farm off-takes and bringing transformative changes to include more lucrative crops, allowing for income growth that is crucial for paying for education and human health needs. Improved water productivity, through more strategic use of water and nutrients will ensure overall sustainability of the system. The involvement of the local government is crucial to achieving success. The private sector is involved in both input supply as well as output market development.

5. EXCHANGES OF PGRFA

5.1 Flows in and out of the National Gene Bank of Zimbabwe

The Genetic Resources and Biotechnology Institute (GRBI), which houses the National Gene Bank of Zimbabwe (GBZ), uses the Standard Material Transfer Agreement (SMTA) for germplasm exchange purposes. Improved and conserved seed is available to any research institution, worldwide. The GBZ conserves germplasm at two levels: the first level is the base collection and the second level is the active collection. Base collections are kept as a backup for the active collection and are usually conserved on a long-term basis. Active collections have short-term conservation objectives and are mainly used as materials for distribution to breeders, researchers and farmers.

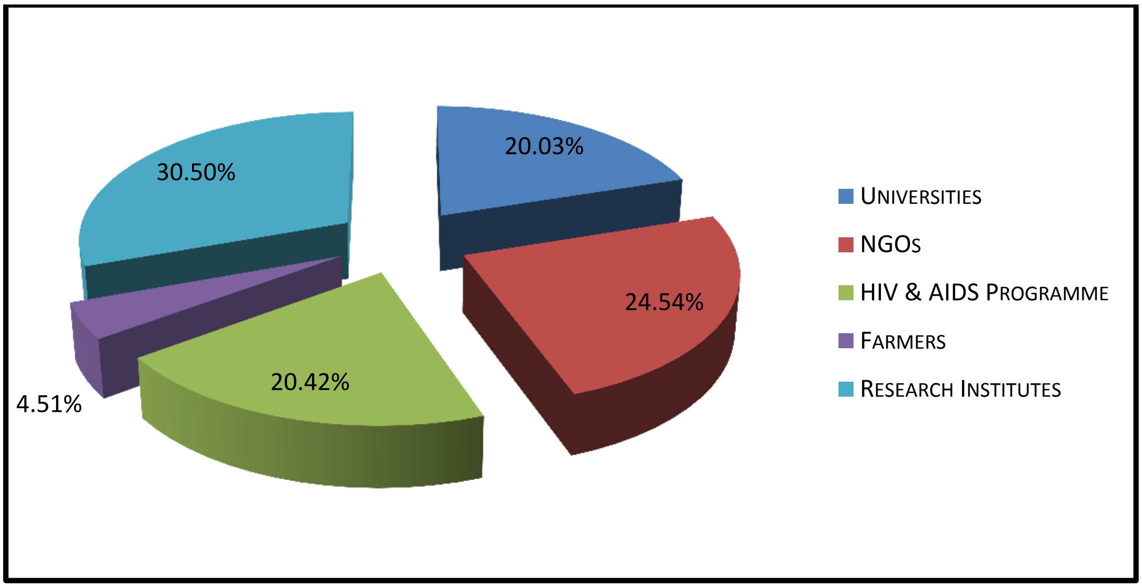
Demand for *ex situ* collections in the GBZ has been inconsistent over the years (Table 4). This could be due to the fact that potential users of the materials are either not aware of the facility, or because of a lack of information required by researchers and breeders on the materials in the *ex situ* collection. However, there have been increases in recent years (2012 - 2014) as a result of a campaign to promote the utilization of germplasm for a healthy diet for HIV/AIDs patients, through displays at agricultural shows and seed fairs. Some of the ex-situ germplasm collections were accessed by researchers interested in carrying out studies for academic motives. Most of the accessions were distributed to research institutes for breeding and characterization purposes, with the rest of the accessions sent to non-governmental organizations (NGOs), HIV/AIDs programmes, universities and, finally, directly to farmers (Figure 15).

Table 4. Number of accessions distributed from 2001-2014

Year	**Types of crops**				**Total**
	Cereals	*Legumes*	*Vegetables*	*Wild sorghum*	
2001		15	5	4	24
2002	5	2	2		9
2003	10				10
2004					
2005					
2006					
2007	32	24	2		58
2008	19	22	9		50
2009					
2010					
2011					
2012	20	21	78		119
2013	102	171	82		355
2014	21	112	6		139
Total	**209**	**367**	**184**	**4**	**764**

Source: National Gene Bank of Zimbabwe (2015)

Figure 15. Distribution of plant genetic material from the GBZ



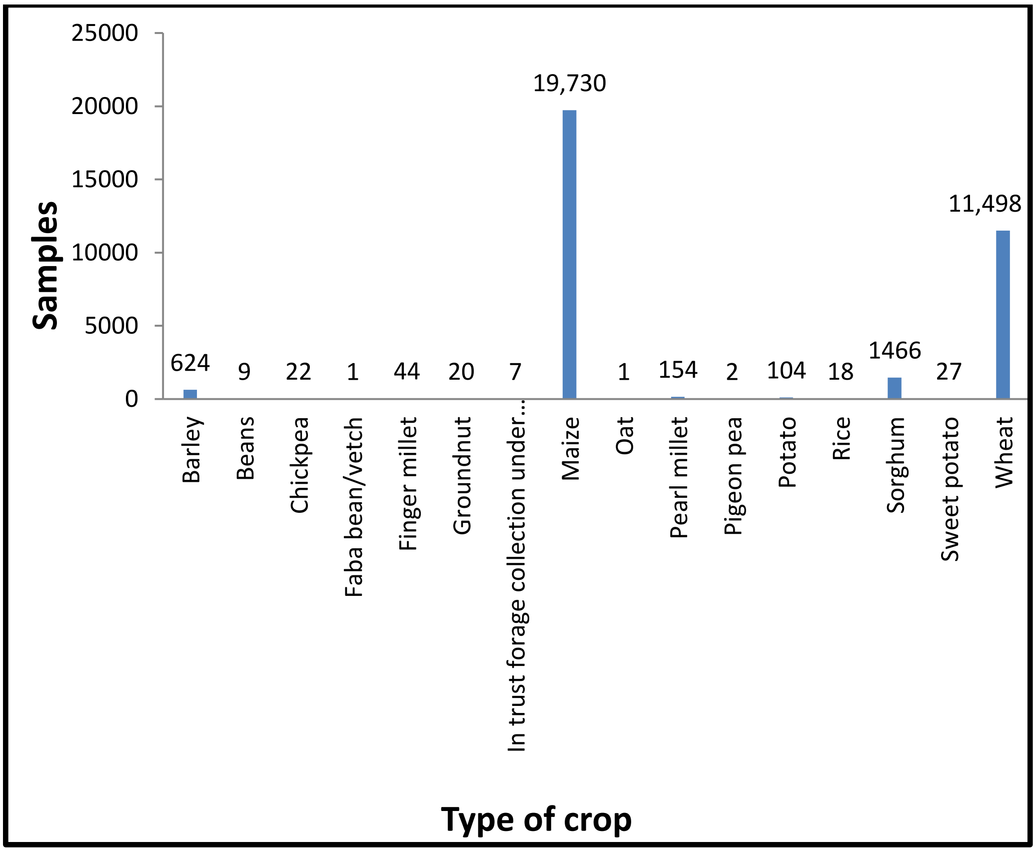
Source: National Gene Bank of Zimbabwe (2015)

5.2 Flows in and out of CGIAR centres

The SMTA was adopted by the Governing Body of the ITPGRFA at its First Session in June 2006, to facilitate the transfer of PGRFA of crops and forages listed in its Annex 1. In the second session of the Governing Body, it was agreed that CGIAR centres could sign agreements to place all their collections in the multilateral system of access and benefit sharing (MLS) of the ITPGRFA, allowing for the transfer of non-Annex 1 accessions held by the centres using the SMTA, in accordance with Article 15. Consequently, germplasm flows out of CGIAR centres, such as CIMMYT, IITA, the International Center for Agriculture in Dry Areas (ICARDA), the Africa Rice Center (AfricaRice) and ICRISAT, into Zimbabwe are facilitated using the SMTA.

The crop genetic resources exchanged among stakeholders in Zimbabwe included barley, beans, chickpea, faba bean/vetch, finger millet, groundnut, the in-trust forage collection under the ITPGRFA, maize, oat, pearl millet, pigeon pea, potato, rice, sorghum, sweet potato, and wheat. Among the crops exchanged, maize, wheat, sorghum and barley had the highest number of accessions, in order of preference (Figure 14). The purposes of the germplasm exchange between CGIAR centres, and with other stakeholders, are indicated in the sub-headings below.

Figure 14. Total number of samples exchanged per crop by stakeholders in Zimbabwe



Source: Community Technology Development Organisation (CTDO)

5.3 Exchange of germplasm between ICRISAT and other stakeholders

Staple food grains are the first priority of the poor because their very lives depend on them, particularly the dryland cereals. Investing extensively in sorghum and pearl millet genetic resources, through research to improve these crops, will continue to help farmers capitalize on within-crop diversity to reduce risk.

Germplasm exchange for the various research initiatives has been facilitated using the SMTA (Table 5).

Table 5. Germplasm exchange between ICRISAT and stakeholders

Year	Crop	Quantity	Type	Receiving co.	Purpose	Agreement
2004	Sorghum	272	Landrace	CRS*	Research	SMTA
	Sorghum	51	Breeding line	CRS*	Research	SMTA

2005	Sorghum	1	Breeding line	MAR*	Research	SMTA
	Sorghum	41	Breeding line	CBI*	Research	SMTA
	Pearl millet	64	Landrace	CBI*	Research	SMTA
	Pearl millet	2	Breeding line	CBI*	Research	SMTA
	Sorghum	44	Breeding line	Progene Seeds	Research	SMTA
2006	Sorghum	2	Breeding line	CBI*	Research	SMTA
	Sorghum	114	Landrace	CBI*	Research	SMTA
	Sorghum	4	Breeding line	UZ*	Research	SMTA
2007	Sorghum	3	Breeding line	CBI*	Research	SMTA
	Sorghum	19	Breeding line	NUST*	Research	SMTA
2008	Pearl millet	5	Breeding line	Progene Seeds	Research	SMTA
	Sorghum	30	Breeding line	Progene Seeds	Research	SMTA
2009	Sorghum	25	Breeding line	Progene Seeds	Research	SMTA
2010	Sorghum	2	Breeding line	Progene Seeds	Research	SMTA
	Sorghum	22	Breeding line	SeedCo	Research	SMTA
	Pearl millet	64	Landrace	CBI*	Research	SMTA
	Pearl millet	2	Breeding line	CBI*	Research	SMTA
	Pearl millet	1	Breeding line	CwDCC*	Research	SMTA
	Sorghum	1	Breeding line	CwDCC*	Research	SMTA
	Pearl millet	1	Breeding line	Plan International	Research	SMTA
	Sorghum	1	Breeding line	Plan International	Research	SMTA
	Sorghum	3	Breeding line	FAOZIM*	Research	SMTA
	Pearl millet	3	Breeding line	FAOZIM*	Research	SMTA
	Groundnut	1	Breeding line	FAOZIM*	Research	SMTA
2011	Sorghum	40	Breeding line	SeedCo	Research	SMTA
	Sorghum	1	Breeding line	CwDCC*	Research	SMTA
	Pearl millet	2	Breeding line	CwDCC*	Research	SMTA
	Sorghum	1	Breeding line	Progene Seeds	Research	SMTA
	Groundnut	1	Breeding line	Progene Seeds	Research	SMTA
2012	Sorghum	33	Breeding line	SIRDC*	Research	SMTA
	Finger millet	13	Landrace	SIRDC*	Research	SMTA
	Pearl millet	66	Landrace	SIRDC*	Research	SMTA
	Pearl millet	6	Breeding line	SIRDC*	Research	SMTA
	Sorghum	10	Breeding line	ARI*	Research	SMTA
	Sorghum	61	Landrace	NUST*	Research	SMTA
	Sorghum	1	Landrace	NUST*	Research	SMTA

	Sorghum	1	Breeding line	NUST*	Research	SMTA
	Sorghum	6	Breeding line	AU*	Research	SMTA
2013	Sorghum	160	Landrace	CBI*	Research	SMTA
	Sorghum	3	Breeding line	CBI*	Research	SMTA
	Sorghum	6	Breeding line	SeedCo	Research	SMTA
	Sorghum	3	Breeding line	NUST*	Research	SMTA
	Sorghum	1	Breeding line	ZimCLIFFS*	Research	SMTA
	Pearl millet	1	Breeding line	CBI*	Research	SMTA
	Sorghum	2	Breeding line	ICRISAT Malawi	Research	SMTA
	Sorghum	1	Breeding line	CBI*	Research	SMTA
	Pearl millet	1	Breeding line	MRS*	Research	SMTA
	Sorghum	1	Breeding line	ICRISAT Matopos	Research	SMTA
	Sorghum	128	Breeding line	Shungu High School	Research	SMTA
	Sorghum	1	Breeding line	CBI*	Research	SMTA
	Pearl millet	4	Breeding line	CBI*	Research	SMTA
	Sorghum	65	Landrace	LSU*	Research	SMTA
	Sorghum	4	Breeding line	SeedCo	Research	SMTA
	Sorghum	39	Landrace	SeedCo	Research	SMTA
	Sorghum	1	Breeding line	CBI*	Research	SMTA
	Pearl millet	4	Breeding line	CBI*	Research	SMTA
	Sorghum	9	Breeding line	WUA*	Research	SMTA
	Sorghum	903	Landrace	WUA*	Research	SMTA
2014	Sorghum	1	Breeding line	Prime Seeds	Research	SMTA
	Chickpea	11	Breeding line	CBI*	Research	SMTA
	Sorghum	3	Breeding line	CBI*	Research	SMTA
	Groundnut	5	Breeding line	CBI*	Research	SMTA

Source: ICRISAT, Matopos

*Key: ARI – Agronomy Research Institute; AU – Africa University; CBI – Crop Breeding Institute; CRS – Chiredzi Research Station; CwDCC – Coping with Drought and Climate Change Project; FAOZIM – FAO Zimbabwe; LSU – Lupane State University; MAR – Melkassa Agricultural Research Centre; MRS – Matopos Research Station; NUST – National University of Science and Technology; UZ – University of Zimbabwe; WUA – Women's University in Africa.

5.4 PGR exchanges between CIMMYT, IITA and other stakeholders

Maize is Zimbabwe's staple food crop, with an annual maize grain requirement of 1.8 million tonnes (Mashingaidze, 2006). The maize crop is the most widely grown in the country by communal, small- and large-scale commercial farmers. Although average yields used to be 1 - 1.5 t/ha in the past (Bänziger and Cooper, 2001), recently they have dropped to around 0.4 t/ha. This is mainly due to recurrent droughts, pests and diseases, lack of fertilizers, lack of varieties that are adaptive to climate change, and lack of farmer knowledge on varieties that are suitable for their prevailing environment.

Maize research in Zimbabwe incorporates a wide range of maize industry stakeholders, focusing mainly on the delivery of improved varieties and technologies to farmers as a way of enhancing food security, whilst also contributing to economic development in southern Africa. Its specific objectives are:

- To develop stress-tolerant maize, and more nutritious varieties that address the needs of resource-poor farmers.
- To develop and stimulate the use of maize varieties with increased productivity, nutritional value and acceptance under the stress-prone conditions of resource-poor farmers.
- To increase the availability of quality seed, particularly in outlying areas.
- To actively support the implementation of seed laws and regulations.
- To strengthen stakeholders' cooperation in the maize seed sector, working towards a more diverse and more stable seed industry that responds to the needs of resource-poor farmers.

Maize research in Zimbabwe began as a measure to address low productivity resulting from recurrent incidences of droughts, as they were a major constraint to the productivity of smallholder farmers. Research was supported by seed exchanges between CIMMYT, IITA and national programmes (Table 6). Apart from maize, IITA and the Crop Breeding Institute (CBI) exchanged germplasm of cowpea and bambara nut for research purposes.

Table 6. Germplasm exchange between CIMMYT, IITA and CBI

Year	Crop	Quantity	Type	Source	Receiving co.	Purpose	Agreement
*1997-2015	Maize	150-200 Hybrids and OPVs annually	Drought tolerant (DT)	CIMMYT	CBI	Research	SMTA
*2009-2013	Maize	100-150 Hybrids	Insect resistant (IR)	CIMMYT	CBI	Research	SMTA

		annually					
2006	Maize	10 Lines	Quality protein maize (QPM)	CIMMYT	CBI	Research	SMTA
2010	Maize	16 Lines	IR	CIMMYT	CBI	Research	SMTA
2011	Maize	14 lines	DT	CIMMYT	CBI	Research	SMTA
2012	Maize	10 Lines	Heat tolerant and DT	CIMMYT	CBI	Research	SMTA
2014	Maize	9 Hybrids	Pro-vitamin A (ProA)	CIMMYT	CBI	Research	SMTA
2014	Maize	36 Lines	ProA	CIMMYT	CBI	Research	SMTA
2015	Maize	4 Hybrids	ProA	CIMMYT	CBI	Research	SMTA
2015	Maize	3 Trial kits	ProA	CIMMYT	CBI	Research	SMTA
2015	Maize	4 Hybrids	DT	CIMMYT	CBI	Research	SMTA
2015	Maize	3 Hybrids	QPM	CIMMYT	CBI	Research	SMTA
*1980-2015	Wheat	100-150 Lines annually	Spring bread and durum wheat	CIMMYT	CBI	Research	SMTA
2009	Maize	33 Lines	Disease resistant	IITA	CBI	Research	SMTA
2013	Maize	31 Lines	ProA	IITA	CBI	Research	SMTA
2010	Cowpea	54 Lines	Landraces and lines	IITA	CBI	Research	SMTA
2015	Cowpea	28 Lines	Landraces and lines	IITA	CBI	Research	SMTA
2015	Bambara nut	49 Lines	Landraces	IITA	CBI	Research	SMTA

Source: CBI

Key: * denotes range of period, and absence of data aggregation by year.

5.5 Germplasm exchange between CBI and CGIAR centres

Germplasm exchanges between CGIAR centres (CIAT, ICARDA and AfricaRice) and the breeding programmes of CBI have been carried out using the SMTA. The exchanges were linked to agricultural production, including commercial production, conservation, breeding, training, and research for food and agriculture. For the national programmes run by CBI, germplasm sent from CIAT, mainly beans, was requested for the purposes of research for breeding (Table 7).

The National Bean Programme of DRSS comprises the following specific research areas:

- Integrating pest and disease management in beans.
- Integrating soil fertility and water management in beans.
- Screening bean germplasm for enhanced biological nitrogen fixation with and without rhizobia inoculation.
- Improving the livelihoods of smallholder farmers in drought-prone areas through enhanced grain legume production and productivity-tropical legumes.
- Improving tropical legume productivity for marginal environments.

Furthermore, Zimbabwe runs the National Bean Programme, gathering agronomic information on the effect of intercropping maize with beans, water harvesting, and the use of fertilizer versus manure in beans.

Table 7. Germplasm exchange between CIAT, ICARDA, AfricaRice and national programmes (DRSS – CBI)

Year	Crop	Quantity	Type	Source	Receiving co.	Purpose	Agreement
2009	Beans	277	Breeding line	CIAT	CBI	Research	SMTA
2010	Beans	165	Breeding line	CIAT	CBI	Research	SMTA
2011	Beans	260	Breeding line	CIAT	CBI	Research	SMTA
2012	Beans	356	Breeding line	CIAT	CBI	Research	SMTA
2013	Beans	510	Breeding line	CIAT	CBI	Research	SMTA
2014	Beans	444	Breeding line	CIAT	CBI	Research	SMTA
2015	Beans	905	Breeding line	CIAT	CBI	Research	SMTA
2013	Wheat	192	Breeding line	ICARDA	CBI	Research	SMTA
2014	Wheat	157	Breeding line	ICARDA	CBI	Research	SMTA
2015	Wheat	90	Breeding line	ICARDA	CBI	Research	SMTA
2004	Rice Nerica	7	Upland rice Lines	AfricaRice	CBI	Research	SMTA
2013	Rice	50	Upland rice Lines	AfricaRice	CBI	Research	SMTA

Source: Crop Breeding Institute (CBI)

5.6 Flows in and out of breeding programmes

Zimbabwe does not have an established network of plant breeders, and as such there is no meaningful flow of genetic material in and out of breeding programmes. Both national breeding programmes (public) and the private sector conduct their breeding independently, and only share with CIMMYT to allow for regional germplasm movement for variety testing and evaluation, as an essential step in the recognition and release of new, improved varieties. Every year, CIMMYT conducts regional trials that test new hybrids and OPVs in the diverse mega-environments of southern Africa. These trials are categorized according to variety type (OPV or hybrid) and maturity (early-intermediate or intermediate-late). Each year, over 100 varieties from CIMMYT, NARS and the private sector are tested (Table 8). CIMMYT contributes the majority of varieties in these trials, and this proportion has increased in recent years (Table 9). The movement of germplasm for regional evaluations greatly depends on the willingness of the interested parties; the outputs from these trials are published annually by CIMMYT and made freely available to interested parties.

CIMMYT varieties are only entered into consecutive regional trials if they have performed extremely well in the first year of testing. Generally, two years of testing give a good indication of variety performance, and thus the regional trial results provide good information for the selection of improved varieties for advancement and registration.

Table 8. The source of varieties in the CIMMYT regional trials, 2005 - 2009

Source (from)	Country	2004/5	2005/6	2006/7	2007/8	2008/9
Afgri Seeds	South Africa				3	3
Agricultural Research Council – Grain Crops Institute (ARC-GCI)	South Africa	3				
DRSS-CBI	Zimbabwe	7			2	2
Department of Agricultural Research Services (DARS)	Malawi				2	3
CIMMYT	-	82	75	86	134	130
Capstone Seeds	Zimbabwe	5				

Institute for Agricultural Research (IIA)	Angola	1				
Mauritius	Mauritius	1				
Monsanto	South Africa	5				
Nelson Genetics	South Africa	2	1	2		
Pannar	South Africa	1	5	2	6	4
Pioneer	Zimbabwe	5	7	4	4	1
SARI	Tanzania	2				
Seed-Co Ltd	Zimbabwe	11	8	6	7	7
Pristine Seeds	Zimbabwe			4	2	
Western Seeds	Kenya	6	5		6	
Zamseed	Zambia	13		5	7	8
Total		**144**	**101**	**109**	**173**	**158**

Source: CIMMYT (2008)

Table 9. The proportion of varieties in the CIMMYT regional trials provided by CIMMYT, the private sector and NARS, 2004 to 2009

Source	2004/5	2005/6	2006/7	2007/8	2008/9
CIMMYT	57%	74%	79%	77%	82%
Private sector	33%	26%	21%	20%	15%
NARS	10%	0%	0%	2%	3%

Source: CIMMYT (2008)

Regional variety testing allows varieties that do well in wider agro-ecologies across the countries of the South African Development Community (SADC) to be released easily, as the agronomic data gathered are from various member states. Each country can therefore benefit from both specific and general agronomic data, which contributes to determining the value for cultivation and use (VCU), one of the requirements for variety release in member states. Of all the varieties registered in 2008, a total of 15 originated from CIMMYT: eleven OPVs and four hybrids, of which seven were registered by NARS, and eight by the private sector. Thus, CIMMYT germplasm plays a significant role in the provision of improved varieties in the seed sector, and both NARS and the private sector are benefitting from this germplasm. Currently in southern Africa, ZM421, ZM521 and ZM623 are the most widely registered OPVs (Table 10). The challenges associated with regional germplasm movement are linked to different seed laws in member states, which may delay the process of movement and also the pace of implementing the SADC Harmonized Seed Regulatory System.

Table 10. CIMMYT OPVs released in SADC countries

Variety	SADC countries/holder of the registration – *names in brackets indicate the locally registered name of the CIMMYT OPV*									
	AO*	**CD***	**LS***	**MW***	**MZ***	**ZA***	**SZ***	**TZ***	**ZM***	**ZW***
ZM309							CAR**			
ZM401								Tanseed (TAN250)		
ZM421	IIA		DAR **	DARS	IIAM** (Djandza)	ARC-GCRI (ZM1421)		SARI** (Situka-1)	ZARI-GVRC**	DRSS-CBI
ZM423	IIA		DAR			ARC-GCRI (ZM1423)			Kamano Seeds	Chemco Seed
ZM521	IIA		DAR	DARS		ARC-GCRI	CAR	SARI (Situka-2)	ZARI- GVRC	DRSS-CBI
ZM523						ARC-GCRI (ZM1523)				SeedCo (Chitima)
ZM611				DARS		ARC-GCRI (ZM1611)	CAR			
ZM621	IIA			DARS	IIAM (Tsangano)				ZARI- GVRC	
ZM623	IIA	UNILU**	DAR	DARS		ARC-GCRI (ZM1623)		SARI (Vumilia K1)		SeedCo (Chariot)
ZM625									Kamano Seeds	
ZM721		UNILU (Katanga)		DARS				Tanseed (TAN254)	Kamano Seeds	

Source: CIMMYT (2008)

*Country key: AO – Angola; CD – Democratic Republic of the Congo; LS – Lesotho; MW – Malawi; MZ – Mozambique; ZA – South Africa; SZ – Swaziland; TZ – Tanzania; ZM – Zambia; ZW – Zimbabwe.
**Organization key: CAR – Cereals Agronomy Research, Swaziland; DAR – Department of Agricultural Research, Lesotho; IIAM – Agricultural Research Institute of Mozambique; SARI – Selian Agricultural Research Institute, Tanzania; UNILU – Faculty of Agronomic Sciences, University of Lubumbashi, DR; ZARI-GVRC – Zambian Agriculture Research Institute – Golden Valley Agricultural Research Trust

5.7 Genetic resources exchanges between communities and NGOs

In Zimbabwe, there are no genetic flows between projects; germplasm flows have always been from the CGIAR centres to various projects in the country (see Table 11, an extract from Table 5). Due to the effect of climate change, crops such as pearl millet, sorghum and groundnut have often been used by developmental partners and NGOs for the benefit of communities living in marginalized areas.

Table 11. Germplasm exchange from ICRISAT linked to projects in Zimbabwe (extract from Table 5)

Crop	Quantity	Type	Receiving co.	Purpose	Agreement
Pearl millet	1	Breeding line	CwDCC	Developmental project	SMTA
Sorghum	1	Breeding line	CwDCC	Developmental project	SMTA
Pearl millet	1	Breeding line	Plan International	Developmental project	SMTA
Sorghum	1	Breeding line	Plan International	Developmental project	SMTA
Sorghum	3	Breeding line	FAOZIM	Developmental project	SMTA
Pearl millet	3	Breeding line	FAOZIM	Developmental project	SMTA
Groundnut	1	Breeding line	FAOZIM	Developmental project	SMTA
Sorghum	1	Breeding line	CwDCC	Developmental project	SMTA
Pearl millet	2	Breeding line	CwDCC	Developmental project	SMTA
Sorghum	1	Breeding line	Zimcliffs	Developmental project	SMTA

Source: ICRISAT, MATOPOS

6. ACCESS AND BENEFIT SHARING OF PGRFA IN ZIMBABWE

6.1 Policy and legal framework for accessing and exchanging genetic resources in Zimbabwe

Zimbabwe signed and ratified the ITPGRFA on 30 October 2002, and 5 July 2005 respectively, becoming a full contracting party. However, the process of domesticating the ITPGRFA at national level, through the formulation of appropriate legislation and policies, has been very slow. The GRBI, which houses the GBZ, is the 'Competent Authority' for the ITPGRFA; while the Director of Research Services Division, and the Curator of the GBZ, comprise the ITPGRFA focal point, which is responsible for granting permission to access materials using the SMTA.

There are several pieces of legislation regulating access to genetic resources in Zimbabwe, which fall under different sectoral ministries. Seed Services, an institute in DRSS, regulates access to seed in the formal system, through the Seed Act of 1971 (Chapter 19:13) and the Plant Breeders Rights Act (Chapter 18:16). The informal seed supply system involves the saving and sharing of seed by family, friends and neighbours, and scales up to local markets at national level (Garwe, Munzara-Chawira and Kusena, 2009). This supply system is dependent on the cultural heritage principle that supports the farmers' right to save, sell and exchange germplasm amongst themselves. There are also some NGOs involved in the informal seed supply system of Zimbabwe that distribute seed to farmers through seed fairs and seed-pack handouts. There are, however, no specific policies that promote farmers' rights to sell their germplasm in formal markets. The regulation of access to PGR is mainly provided for under the Environmental Management Act (Chapter 20:27), which empowers the Minister for the Environment and Natural Resources to formulate regulations on the conservation of, and access to, biological diversity. Section 116 of the Environmental Management Act (Chapter 20:27) mandates the minister to take such measures as deemed necessary for the conservation of biological diversity and implementation of Zimbabwe's obligations under the CBD. The minister is also mandated to protect the indigenous property rights of local communities in respect of biological diversity; to support the integration of traditional knowledge on the conservation of biological diversity; and to prohibit or restrict access to, or the export of any component of, biological diversity of Zimbabwe.

An analysis of the above provisions shows the top-down nature of the environmental laws of Zimbabwe. They also illustrate the central nature of tenure systems in access- and benefit-sharing (ABS) regulations, in that while indigenous property rights of communities are being promoted, the access to and control over resources is centralized and lies with the ministry responsible for the conservation of biodiversity. Furthermore, draft regulations on access to biological diversity and the protection of traditional practitioners' rights, which are currently in place, do not adequately include issues on PGRFA. The development of any regulations in the future must include consultation with local communities, and their involvement in the decision-making processes.

6.2 Benefits arising from access to and exchange of PGRFA

Breeders and researchers in Zimbabwe, through participation in regional and international programmes, benefit from access to germplasm and improved varieties, technology transfer, and scientific collaboration and capacity building. Farmers benefit by accessing seeds through the functional seed value chain, in which farmers are the ultimate consumers of seed of commercialized, improved varieties. This is evidenced by the ten-year National Seed Initiative for Maize in Africa (NSIMA) project administered by CIMMYT, which contributed to the release of six DT hybrids and three DT OPVs through CBI. Varieties released by CBI were contracted to nine private seed companies for seed multiplication, resulting in a cumulative estimated contribution of more than 136,602 tonnes of certified seed for the ten-year period (2005 - 2015). Private seed companies released eleven hybrids and two OPVs, for commercial seed production (Table 12). The availability of varieties released through NSIMA for commercial seed production was pivotal to improving seed security of resource-poor farmers.

Table 12. Maize varieties released over the period 2005-2015

Year	**NSIMA/DTMA varieties**		**Other maize varieties**	**Total Released**
	Public (CBI)	*Private (seed companies)*	*Private (seed companies)*	
2005	Commencement of NSIMA			
2006	ZS 261	PGS 61, PGS 53	ZM 423, SC721, SC 608 PGS 71 PHB 30B50	8
2007			PAN 7M-89, PAN 63, PAN 4M-19, PAN 8M -95, PAN 7M-97 SC 407, SC 533	7
2008		PHB 30G19 ZAP 51, ZAP 61	PHB 30V53, PHB 30D79 SC 535	6
2009	ZM 401 ZM 309		P2859W	3
2010		SC 727	PAN 4M-21, SIRDA 113, PRIS 601	4
2011	ZS 265 ZS 263		SC 537, SC 708, SC 402 MRI 455, MRI 514, MRI 614, MRI 624, MRI 634	10
2012		SC 301	SC 643, SC 417, SC 529	4
2013		PGS 63, PGS 51	PAN 7M-81, PAN 3M-41 ZAP 71, PAN 12	6
2014	ZS 269 ZS 271 ZS 273 ZS 275	MUTSA MN521, MAMA MQ623 NTS 41, NTS 51	PGS 57, PGS 65	10
2015			SC 303, SC 419, SC649 CAP 9001, CAP 341NG, Nelson's Choice	6
Total	**9**	**13**	**43**	**65**

Source: DRSS (2005-2011; 2011-2014)

When benefits are accrued as the result of the exchange and use of public germplasm (held by CGIAR centres and NARS), and even private germplasm, these benefits should be shared equitably. In Zimbabwe, germplasm exchange between farmers and communities is not documented. There is no mechanism to operationalize the system of documenting germplasm at local level. Furthermore, most of the maize germplasm used in Zimbabwe has its origin outside the borders of Africa. However, many of the maize germplasm accessions now being exchanged in breeding programmes fall under the MLS, and as such their exchange is guided by the SMTA. Smallholder farmers and communities in marginal areas benefit from PGRFA when they access seed from community seed banks or the GRBI/GBZ, exchange seed amongst themselves at seed fairs, and participate in plant breeding and variety selection programmes. Farmers in Zimbabwe will be able to fully benefit from PGRFA conservation and utilization when *sui generis* systems, intellectual property rights and other legal mechanisms to benefit farmers and communities are implemented. Such benefit-sharing mechanisms should put in place incentivizing measures to ensure the cascading of benefits to institutions, communities and individuals.

6.3 Challenges in the implementation of ABS for PGRFA

The main challenges faced in implementing ABS for PGRFA are as follows:

- Absence of a comprehensive policy and legislative framework. This is a major weakness, which is exacerbated by the following:
    - lack of coherence between the National Biodiversity Strategies and Action Plans and national regulatory instruments;
    - difficulties in translating the various articles on ABS into national targets;
    - the increasing economic power of seed companies; and
    - lack of incorporation of indigenous issues and recognition of their level of contribution to breeding.
- Coordination amongst ministries. While the regulation of access to biological resources is vested in the Minister of Environment, Water and Climate (MoEWC), in compliance with the CBD; the MoAMID is obliged to domesticate the provisions of the ITPGRFA. There is a lack of sectoral integration.
- Limited awareness. There is a low level of public knowledge and awareness regarding PGRFA. Most of the farmers, farmers' representatives and institutions that provide services on agro-biodiversity currently do not fully understand the principles of farmers' rights and their ultimate objectives and importance. CBOs think that the formal system criminalizes the informal seed systems, even though there are no evidenced-based studies to suggest this.

Furthermore, civil organizations suggest that the seed of improved varieties from the formal seed system is simply not available in the domain of the smallholder farmers, which leaves one wondering where the notion of criminalization is coming from.

- Pressure from civil organizations to change seed policies that govern the formal seed system, instead of suggesting policies for informal seed systems. Almost all seed companies feel that civil organizations purporting to represent farmers do not know what they want apart from a desire to change policies that promote the formal seed system. The major point is that if the formal and the informal seed systems are to be complementary, civil organizations should come up with policies that guide operations in the informal seed systems to complement existing policies for the formal seed system. The feeling is that the proponents of the informal seed systems want to distort the policies governing the proper operation of the formal seed system.

6.4. Policy initiatives needed to address ABS challenges

In order to domesticate international instruments to which the country is party to, a number of policy-level changes or processes are required to implement ABS mechanisms for facilitating the exchange of PGRFA and information. The most critical of these international instruments are the CBD and the ITPGRFA, which provide mechanisms to protect PGRFA, and promote their sustainable utilization; the Nagoya Protocol is a supplementary agreement to the CBD, focused on ensuring access to PGRFA and the fair and equitable sharing of benefits arising out of their use.

6.4.1 International Treaty on Plant Genetic Resources for Food and Agriculture

Plant genetic resources for food and agriculture are essential to sustainable agriculture and food security. Crop breeding is carried out through farmer selection, conventional plant breeding and the use of modern biotechnology techniques. Countries throughout the world have for many years depended on plant genetic resources developed in other countries. This interdependence on plant genetic resources has acquired both economic and social importance. The ITPGRFA was adopted in 2001 with the aim of recognizing the contribution of farmers to crop diversity; establishing a global system to provide farmers, breeders and scientists with access to genetic materials; and ensuring the benefits derived from the use of those materials are shared fairly and equitably.

The Governing Body of the ITPGRFA is composed of representatives of contracting parties; it is responsible for promoting the implementation of the ITPGRFA, and providing policy guidance. Since Zimbabwe signed and ratified the ITPGRFA on 30 October 2002, and 5 July 2005 respectively, it is hoped that the government will hasten the process of domesticating the treaty at national level through the formulation of appropriate policies and legislation.

6.4.2 The CBD and Nagoya Protocol[9]

The Convention on Biological Diversity (CBD) lies at the heart of biodiversity conservation initiatives. It offers opportunities to address global issues at national level through locally grown solutions and measures. Zimbabwe has been party to the CBD since 9 February 1995, having signed and ratified it on 12 June 1992 and 11 November 1994, respectively. The objectives of the CBD are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

The Nagoya Protocol contributes to the conservation and sustainable use of biodiversity by providing a transparent legal framework for the effective implementation of one of the three objectives of the CBD: the fair and equitable sharing of benefits arising out of the utilization of genetic resources. It was adopted on 29 October 2010 in Nagoya, Japan and entered into force on 12 October 2014, 90 days after the deposit of the fiftieth instrument of ratification.

The Nagoya Protocol will create greater legal certainty and transparency for both providers and users of genetic resources by establishing more predictable conditions for access to genetic resources; and by helping to ensure benefit sharing when genetic resources are taken out of the country that has provided them.

The Nagoya Protocol applies to genetic resources that are covered by the CBD, and associated traditional knowledge (TK), and to the benefits arising from their utilization. Through its benefit-sharing provisions, the Nagoya Protocol provides incentives for the conservation and sustainable of use genetic resources, enhancing the contribution of biodiversity to development and human well-being.

According to interviews with representatives of the seed industry and CGIAR centres, it is clear that the issue of ABS is new, and that it is driven from a civil society organizations' perspective. Most of the seed companies interviewed acknowledged hearing some information on ABS during the African Seed Trade Association (AFSTA) Congress held in February 2015 in Victoria Falls, Zimbabwe. However, the seed companies did not seem to understand how they are affected by ABS legislation. It is common knowledge that public-bred varieties are not protected by plant variety protection legislation in the country. However, the seed companies would like to see no barriers to accessing

[9] This section is based on data from the CBD website: see https://www.cbd.int/abs/about/default.shtml#objective, accessed 1 April 2017.

those PGR held by farmers, public institutions and private organizations. Access is vital as an adaptation strategy to further propel breeding initiatives as we seek response to the changing environment.

7 CLIMATE CHANGE ADAPTATION FOR FUTURE PGR NEEDS IN ZIMBABWE: CASE STUDIES

7.1 Case study of maize variety evaluation using the mother-baby trial approach

In 1998, CIMMYT, together with DRSS and AGRITEX, initiated the National Maize Variety Testing Programme, using the 'mother-baby' trial approach. The aim was to try and bridge the gap between the high yields of maize obtained by the breeders and commercial farmers and the low yields obtained at smallholder farm level. The trials evaluate the performance of new maize varieties (hybrids and OPVs) and their acceptance by smallholder farmers. However, no local or farmer varieties were considered for these trials. Devised by Sieglinde Snapp, of ICRISAT, the 'mother-baby' trial approach was used in a participatory research and extension project where farmers, researchers, extension, seed companies and rural development agents evaluated released and pre-released maize varieties in farmers' fields, in different agro-ecological zones. The project consisted of multi-site trials that allowed farmers and researchers to test the performance of maize varieties and their acceptability by farmers under two types of experiments: a researcher-managed 'mother trial' and a farmer-managed 'baby trial' (Neurashe et al., 2008).

The design facilitated the adoption of superior and appropriate maize varieties. Furthermore, it provided a means to infuse indigenous preferences in maize varieties under the maize programme, with the objective of facilitating the adoption by smallholder farmers of maize varieties that are adapted to their conditions, and ultimately raise and stabilize maize yields in their farming sector.

Varieties evaluated in the 2008/2009 season that consistently showed better yields across all mother-baby trial sites, and which smallholder farmers also selected as preferred varieties, were PAN 53, SC635, AG107, SC403, AG107, PHB3253 and PHB30G19 (Neurashe et al., 2008). With the famine the country experienced in the previous season still fresh in their minds, the farmers' appreciation of the varieties during field days were skewed towards the early-maturing varieties, especially SC403 and VP041. Also of great interest were OPVs because of their affordability and the fact that their seed can be recycled for at least two to three seasons before fresh seed should be bought.

7.2 Case study of PGR adaptation in two farming communities in Zimbabwe

There is emerging empirical evidence that the implications of climate change in Zimbabwe will be dire in the future. According to WorldClim[10], there will be an average increase in temperatures of around 2.5 °C by 2050). The timing and amount of rainfall received in Zimbabwe are becoming increasingly uncertain. There has been an overall decline of nearly 5% in rainfall across the country since 1901, with the early 1990s witnessing probably the driest period of the last century. The frequency and length of dry spells during the rainy season have increased while the number of rainy days has been reducing. Although the overall quantity of annual rainfall may not change much, the rain may fall during violent storms. Rainfall distribution is erratic both in space and time across all the provinces of Zimbabwe. This erratic nature of rainfall patterns has serious adverse impacts (IES, 2014). As such, farmers may need to access germplasm adaptable to such conditions from outside their communities. This germplasm could be found in national gene banks, community seed banks and international gene banks that depend on foreign sources.

7.2.1 Case study methodology

A case study of two reference sites in Zimbabwe was used to demonstrate future challenges regarding climate change, and related PGR needs. The methodology involved the selection of two reference sites, namely Tsholotsho and Uzumba Maramba Pfungwe (UMP). Crop suitability modelling and geographic information system (GIS) tools were used to analyse climate data, and participatory approaches, including scoring and ranking, were used in focus group discussions (FGDs) with farmers to select varieties suitable for climate change adaptation. The process was all-inclusive, with scientists and farmers participating throughout. Through GIS and crop suitability modelling varieties of finger millet and of sorghum were identified from local sources, national gene banks, and international gene banks, by matching varieties from similar climates using relevant bioclimatic variables, these were then multiplied and will be tested by farmers in the two sites.

A total of 19 bioclimatic variables were extracted using the BIOCLIM algorithm, at a resolution of 2.5 arc minutes[11], with the programme DIVA-GIS. Most of these variables were associated with the various precipitation and temperature regimes characteristic of the different habitats of beans. Locality data from accession specimens were used to extract the variables. Agro-ecological variables at each locality were extracted using ArcGIS 10. Each accession was from a unique agro-ecological zone. Since we were clustering the accessions based on three variables (average annual temperature, annual precipitation and agro-ecological zone), we calculated the average annual temperature and

[10] WorldClim global climate data are available at http://www.worldclim.org, accessed 15 January 2017.
[11] An arc minute is a unit of angular measurement equal to one sixtieth (1⁄60) of one degree.

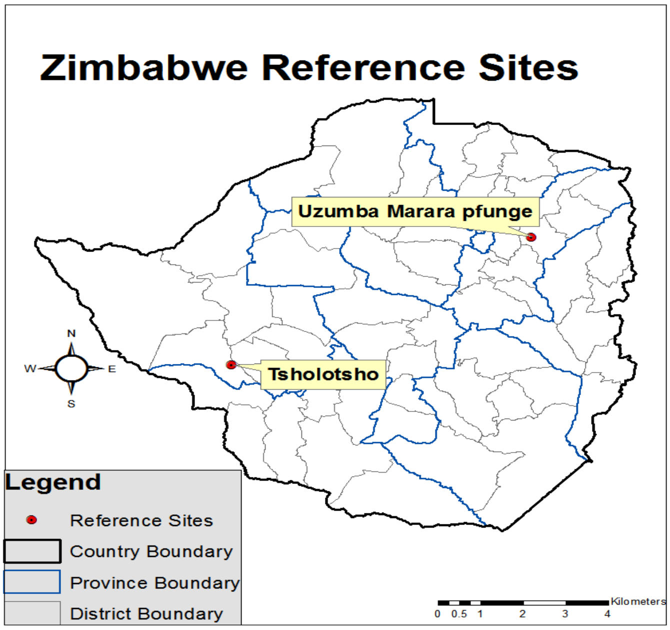
annual precipitation variables using the formulas $((t_{min1}+t_{max1})/2+(t_{min2}+t_{max2})/2+\cdots\cdots+(t_{min12}+t_{max12})/2)/12$ and $(prec_1+prec_2\cdots\cdots+prec_{12})/12$, respectively. Here, t_{min} and t_{max} are the mean monthly minimum and maximum temperatures, respectively and *prec* is the total monthly precipitation.

R software was used to implement a hierarchical clustering method based on the technique proposed by Grum and Atieno (2007) to group the gene bank accessions into different categories on the basis of the average annual temperature, annual precipitation and agro-ecological zone of each accession record.

7.2.2 Climate change in the selected reference sites

The selected reference sites, Uzumba Maramba Pfungwe (UMP) and Tsholotsho, are located in two different agro-ecological zones of Zimbabwe, which experience different climate-related challenges (Figure 16). UMP district spans IIB to IV of Zimbabwe's classification of agro-ecological regions (AERs). The greater part of UMP district (Maramba and Pfungwe) is in AER IV, while about 20% of the district (Uzumba north) is in AER III. Only 16% of UMP (Uzumba south) is in AER IIB. Tsholotsho falls in AER IV. The crops of interest selected were sorghum for Tsholotsho and finger millet for UMP.

Figure 16. Map of Zimbabwe showing the reference sites



In the parts of UMP that are in AER II, climate variability and mid-season droughts are some of the climatic constraints to crop production for smallholder farmers. However, total rainfall and temperature in normal seasons are not usually major limitations to crop production. Most AER II districts receive 800 - 1,000 mm of rain annually; average annual temperatures for most of the UMP district are 20-25 °C (Nyabako and Manzungu, 2012; Vincent and Thomas, 1960). Mean annual temperature projections for the 2050s are between 25 and 27 °C and in some places up to 28 °C. Projections also indicate that there would be a shortening of the growing season, although rainfall amounts in the 2050s may increase by 150 mm annually (Figures 17a and b and Appendix D).

Figures 17a and b. Present and predicted future temperature and precipitation trends in UMP

Figure 17a. UMP, present climate

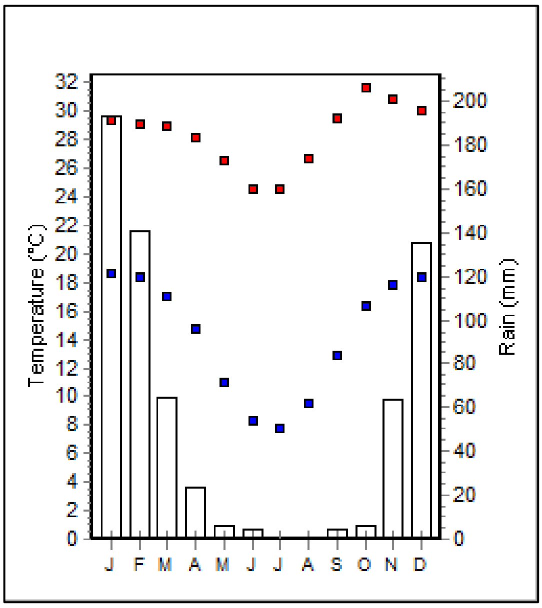
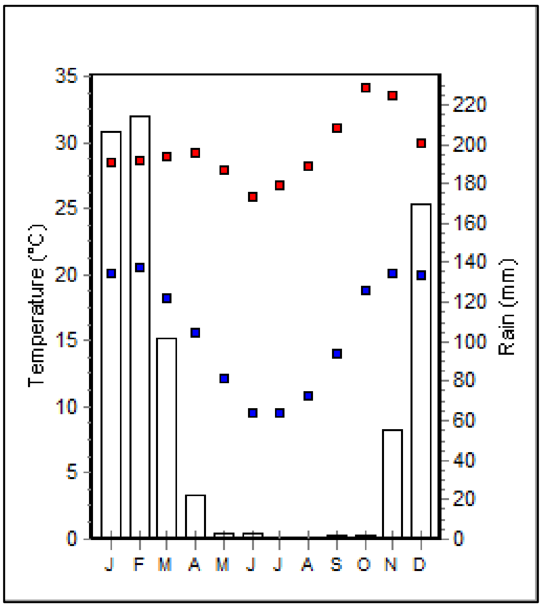


Figure 17b. UMP, 2050's climate



Source: WorldClim

In Thsolotsho, which is in AER IV, low erratic rainfall contributes to low yields in most years. Tsholotsho district receives 450-650 mm of rain annually (Vincent and Thomas, 1960), while the mean temperatures lie between 22 and 27 °C (Nyabako and Manzungu, 2012). Mean annual temperature is projected to be between 25 and 30 °C for most of these districts in the 2050s, while annual rainfall will mostly be below 450 mm. Such a rise in temperature may result in a reduction in yields (Figures 18a and b, and Appendix D).

Figures 18a and b. Present and predicted future temperature and precipitation trends in Tsholotsho

Figure 18a. Tsholotsho, present climate

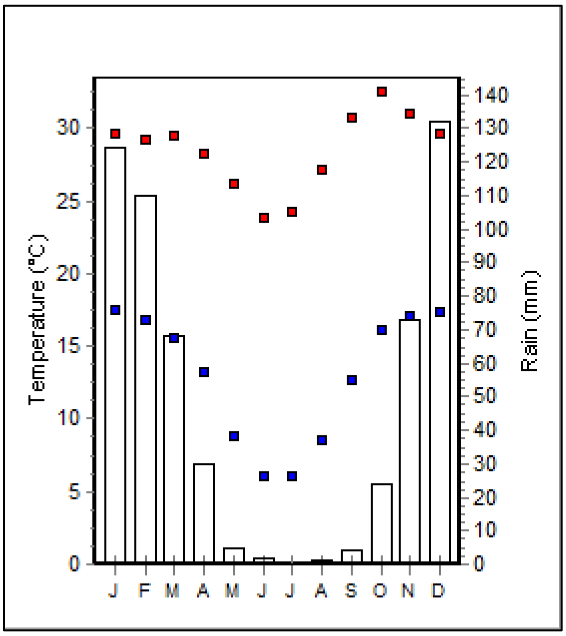
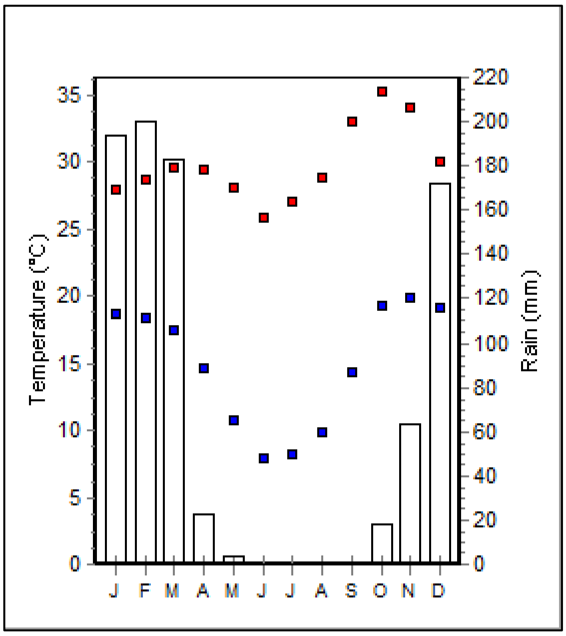


Figure 18b. Tsholotsho, 2050's climate



Source: WorldClim

7.2.3 Results of the case study and accessions selected

Suitable accessions were selected from national and international gene banks using GIS and climate modelling tools. Participatory exercises were also conducted with farmers who identified local varieties that are resilient (Table 13 provides a summary of the results).

Table 13: Sorghum and finger millet accessions from national, international and local sources selected for Tsholothso and UMP, respectively

Reference site	**Crop(s)**	**Accessions in national gene banks**			**Accessions in international gene banks**			**Number of local varieties identified by farmers**
		- total number	***- selected for present climatic conditions***	***- selected for 2050's climatic conditions***	***- total number***	***- selected for present climatic conditions***	***- selected for 2050's climatic conditions***	
UMP	Finger millet	90	29	6	2,279	537	331	7
Tsholotsho	Sorghum	178	31	20	23,941	514	242	7

The maps below (Figures 19, 20, 21 and 22) indicate the number and geographic distribution of the selected accessions. Out of 90 accessions of finger millet from the national gene bank, 29 accessions are suitable for present climatic conditions in UMP, and only six accessions are suitable for the 2050's climate. A clear demonstration that national gene bank collections will not be sufficient to provide the materials needed and countries will have to rely on other countries through the MLS.

Figures 19a, b and c. Maps of GBZ accessions of finger millet for present and 2050's climatic conditions in UMP

Figure 19a

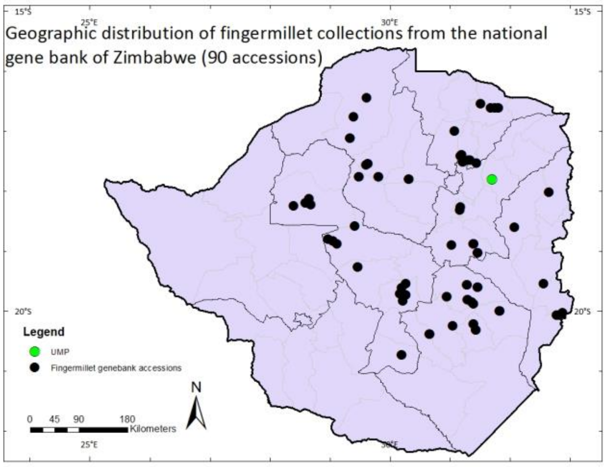
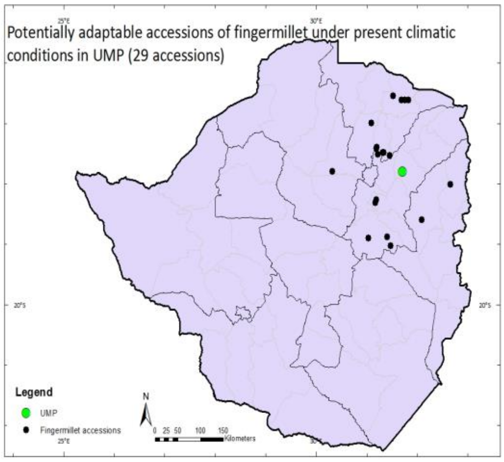
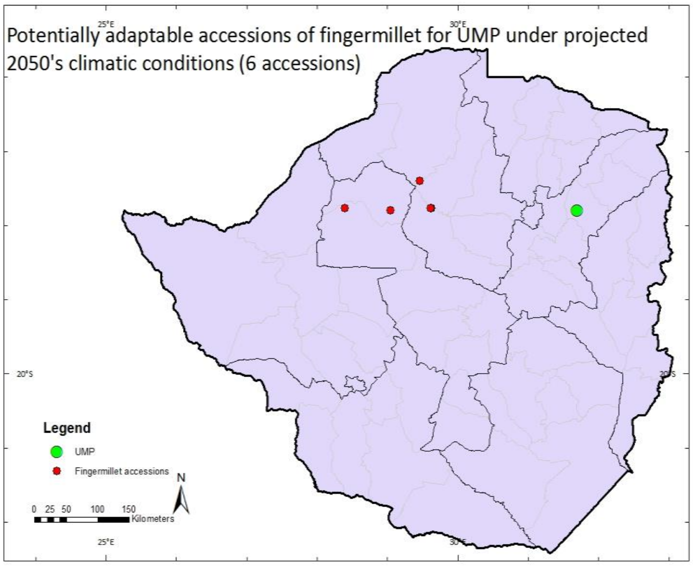


Figure 19b



Source: Gene bank of Zimbabwe

Figure 19c



Source: Gene bank of Zimbabwe

Figures 20a, b and c. Maps of international gene bank accessions of finger millet for UMP

Figure 20a

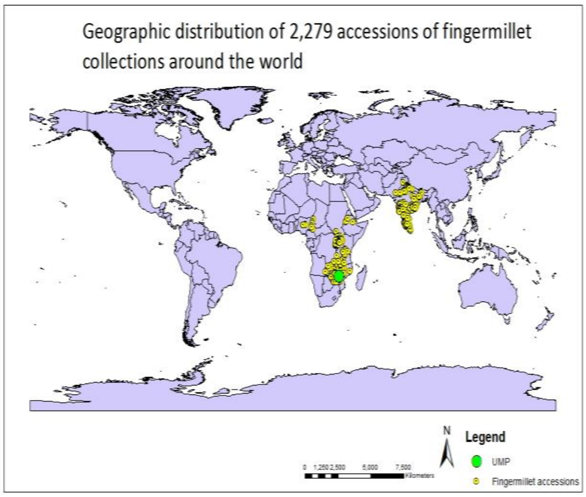
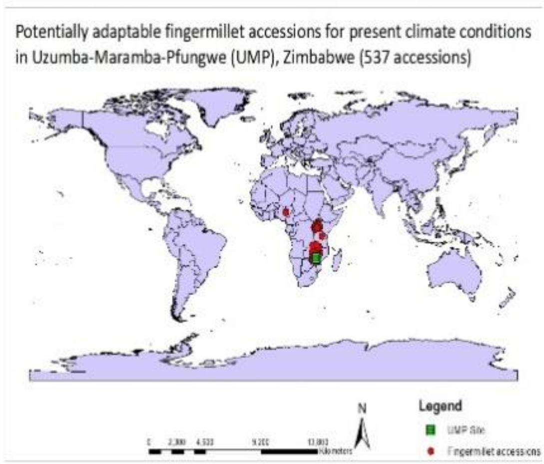
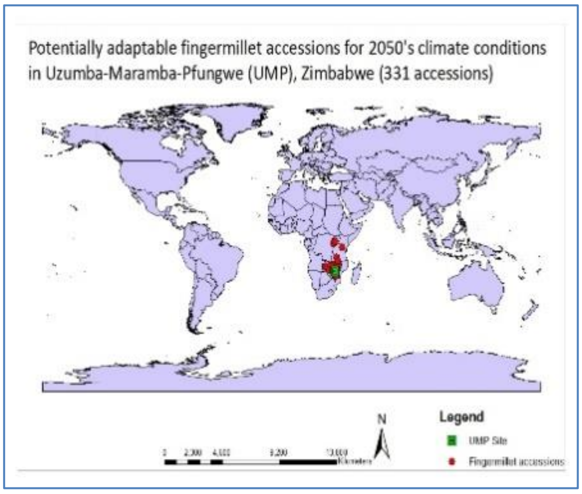


Figure 20b



Source: Genesys

Figure 20c



Source: Genesys

Figure 21a, b and c. Maps of selected national gene bank accessions of sorghum for Tsholotsho

Figure 21a

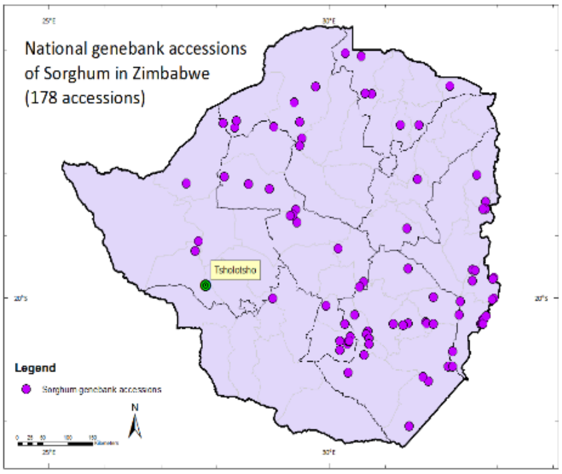
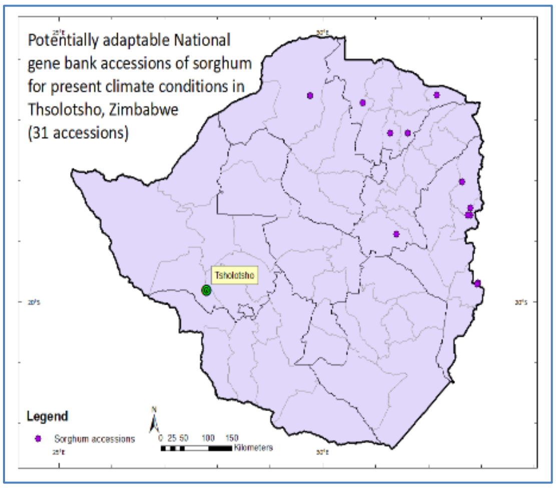
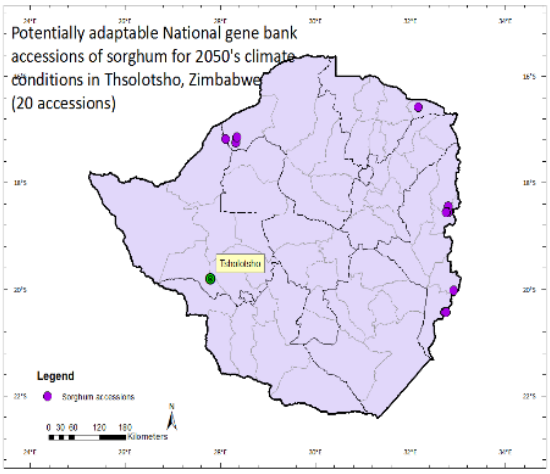


Figure 21b



Source: National gene bank of Zimbabwe

Figure 21 c



Source: National gene bank of Zimbabwe

Figures 22a, b and c. Maps of selected international gene bank accessions of sorghum for Tsholotsho

Figure 22a

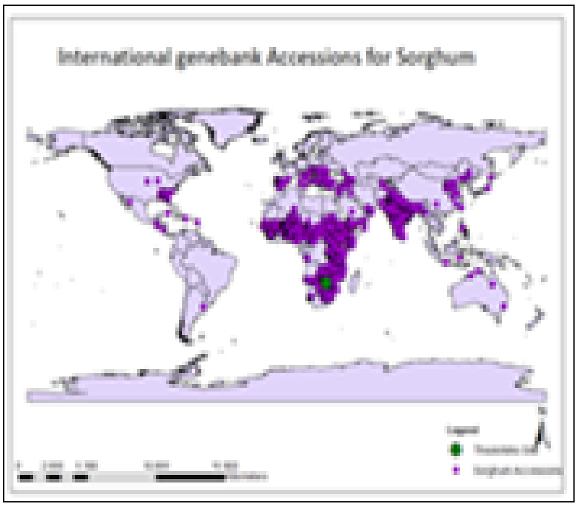
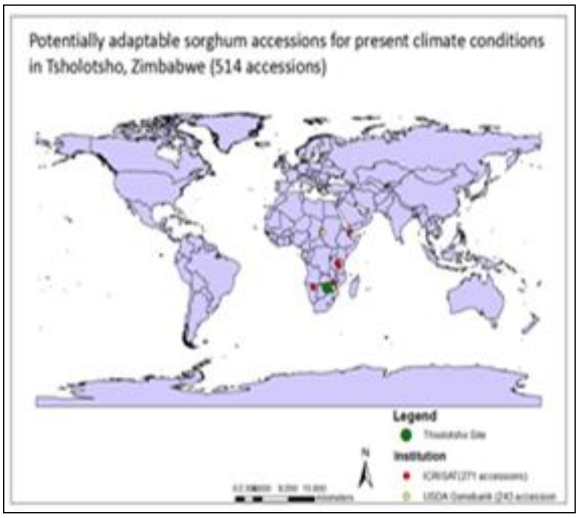
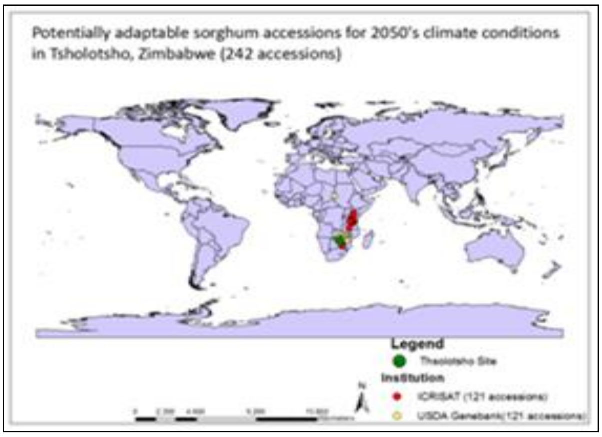


Figure 22b



Source: Genesys

Figure 22c



Source: Genesys

8. CONCLUSION

Climate change is already having negative impacts to food security and poverty in Zimbabwe due to lower productivity, decreases suitability for major staples like maize. Future projections of climate also indicate that temperature increase and reduction in precipitation will further exacerbate the situation and the projected change will result in a reduction of agricultural productivity for the four major crops in the country, with consequential reductions in food security. Maize has a higher sensitivity to the projected climate changes compared to the small grains and pulses. Therefore, adoption of these crops may have considerable potential for strengthening the adaptive capacity of farmers to the negative impacts of climate change.

Current germplasm flows in Zimbabwe show that CGIAR centres play a critical role in providing materials that farmers can use for adapting to climate change, through exchanges with breeding programmes or providing materials directly for evaluation by farmers. Other institutions, such as NGOs and local organizations, act as intermediaries to help farmers access these resources, and to get these materials into the public domain. The role of the national gene bank of Zimbabwe is mainly that of conservation *ex situ*, in addition to a limited number of exchanges with communities or research institutes. Private sector companies are also active in the formal sector through the release of their varieties, which they obtain from the national gene bank or CGIAR centres. A number of research and breeding programmes have worked on releasing varieties of maize, sorghum, finger millet and pulses that are responsive to climate and disease-related challenges, making the seed systems more diverse and resilient.

An analysis of present and future PGRFA requirements in Zimbabwe shows that as climate changes, future germplasm needs will not be sufficiently met by national gene bank of Zimbabwe collections. Zimbabwe will need to rely on genetic material from further afield, with potentially adaptable germplasm located in the collections of ICRISAT, which are freely accessible through the MLS; while other adaptable germplasm can be found in the collections of the United States Department of Agriculture (USDA), which will require further negotiations with the US gene bank to secure access. The policy and legal framework for ABS of PGR, especially with respect to climate change, need to be domesticated, and practical actions must be taken to promote access to and exchange of genetic resources. Zimbabwe has already ratified the ITPGRFA but it still needs to be fully implemented at national level.

Since agricultural production remains the main source of income for most rural communities, adaptation of the agricultural sector to the adverse effects of climate change will be imperative to protect and improve the livelihoods of the poor and to ensure food security. Adaptation will require farmers to make adjustments and employ a range of actions to enhance the resilience of local seed systems that increase their net revenue by reducing the potential damage from climate change. Their capacity to make the required adjustments depends on the existence of policies and investments to support farmers' access to materials and information, as well as to provide the proper economic incentives to stimulate changes. Responding to a changing climate will also require changes in PGRFA management to address both immediate and slow-onset changes. There are a range of adaptation options involving changes in PGRFA management, and diversifying crops, varieties and farming practices. These options are not mutually exclusive, and in fact are most often used in combinations (e.g. changing farming practices also involves changing crops and varieties). Other responses would involve accessing genetic material from further afield, which would mean ABS policies need to be put in place to ensure that farmers can get the materials they need for climate change adaptation.

Recommendations to ensure the effective implementation of ABS for PGRFA include:

- Establishing a comprehensive policy and legislative framework. This is critical for recognizing both the informal and formal sectors of the agricultural industry as important for food security in this changing environment. Furthermore, harmonizing regulations on access and benefit sharing in line with national targets, and recognizing indigenous issues and the extent of their contribution to breeding, is essential. The policy should also seek to streamline the coordination of the different sectoral ministries with respect to the regulation of access to biological resources. Currently, while the MoEWC is in charge of regulating all biological resources, in compliance with the CBD; the MoAMID is responsible for domesticating the provisions of the ITPGRFA. Currently, there is a lack of sectoral integration.
- Awareness raising and facilitating dialogue. Most of the farmers, farmers' representatives and institutions providing services on agro-biodiversity do not yet fully understand the principles of farmers' rights and their ultimate objectives and importance. Raising awareness and discussing the issues is very important, instead of taking divisive approaches that only bring confusion to the farmers.
- Advocating for a seed policy that recognizes both formal and informal seed systems. Currently, a debate is raging between the proponents of the formal and informal seed systems. However, the major point is that both the formal and the informal seed systems should be complementary, and that civil organizations should advocate for government to come up with policies that guide operations in the informal seed systems to complement the existing policies for the formal seed system.

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9. APPENDICES

Appendix A. Detailed description of the methodology used for analyzing current and future climatic changes in Zimbabwe

Historic and current climate patterns for Zimbabwe are summarized from observed data and gridded data created using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping system. PRISM is a unique knowledge-based system that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. This gridded historical dataset is derived from observational data, and provides quality controlled temperature and rainfall values from weather stations worldwide, as well as derivative products including monthly climatologies and long term historical climatologies. The dataset is produced by the Climatic Research Unit (CRU) of University of East Anglia (UEA) (http://www.cru.uea.ac.uk/data), and reformatted by International Water Management Institute (IWMI). Future climate information was derived from available global circulation models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor, Stouffer and Meehl, 2012).

CMIP5 is the fifth iteration of a globally coordinated experiment collection using a previously agreed-upon suite of Representative Concentration Pathways – RCPs (Moss et al. 2010), which reflect different possible futures of distinct emissions, land use change, and associated atmospheric radiative forcing. The scenarios considered in this study are the SRES (Special Report on Emissions Scenarios) A2 and B1 climate change scenarios of the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) (IPCC, 2000; IPCC., 2007). The A2 scenario family describes a very heterogeneous world in which the underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, resulting in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines (IPCC, 2007). We herein refer to this scenario as the Worst Case Scenario (WCS). The B1 scenario, herein referred to as the Best Case Scenario (BCS), is characterized by a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development. Heightened environmental consciousness brought about by clear evidence that impacts of natural resource use, such as deforestation, soil depletion, overfishing, and global and regional pollution, pose a serious threat to the continuation of human life on Earth is also an important feature. In the B1 storyline, the increased attention to the environmental and social aspects of development and technological change by governments, businesses, the media, and the public plays an important role (Solomon et al., 2007). More than 50 distinct models participated in the inter-comparison activity, and many performed multiple simulations for selected scenarios to form ensembles, but only a subset of models completed all of the different scenarios with at least one simulation. Sixteen models that submitted monthly data for all of the RCPs and for which the data were readily available over the Earth System Grid were used in this study (Table A1).

In our analysis, the productivity (or yield per unit area) impact is expressed as the yield 'change'—that is the projected yield for the given future scenario as a percentage change against the current, or baseline, yield. The analysis was conducted for four major food and commodity crops (maize, sorghum, millet and groundnuts) which collectively account for over 80% of total crop production in Zimbabwe (FAO, 2010). Our study focused on the biophysical aspects of climate change impacts on crop productivity (i.e. yield per unit area) and did not consider 'production', as this is dependent on many other 'non-biophysical' factors, such as farmers' management practices, irrigation availability, trade policies and markets. It also ignored the impact of any climate-related shocks, such as floods, droughts and pest attacks on crop productivity. The results were also compared to reviewed studies of climate change impacts on crop production in Southern Africa conducted in the period 2001 - 2015. The impact studies were reviewed through an analysis of major online databases. The review was limited to studies that clearly quantified changes in crop production between present/past and future periods within the 21st century, particularly the mid-century (2040 - 2069) and end of the century (2070 - 2099).

Table A1. List of models used in the study

Model name	**Modelling centre**	**Ocean resolution (°lat × °lon)**	**Atmosphere resolution (°lat × °lon) [km at equator]**	**Main references**
bcc-csm1-1	Beijing Climate Centre, China	1.0 × 1.0	2.8 × 2.8 [310 × 310]	Wu et al. (2013)
bcc-csm1-1-m	Beijing Climate Centre, China	1.0 × 1.0	1.1 × 1.1 [120 × 120]	Wu et al. (2013)
CCSM4	National Centre for Atmospheric Research, USA	1.1 × 0.6	1.2 × 0.9 [130 × 100]	Gent et al. (2011)
CESM1-CAM5	NSF-DOE-NCAR, USA	1.1 × 0.6	1.2 × 0.9 [130 × 100]	Hurrell et al. (2013)
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization, Australia	1.9 × 0.9	1.9 × 1.9 [210 × 210]	Jeffrey et al. (2013), Rotstayn et al. (2012)
FIO-ESM	The First Institute of Oceanography, China	1.1 × 0.6	2.8 × 2.8 [310 × 310]	Qiao et al. (2013)
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, USA	1.0 × 1.0	2.5 × 2.0 [275 × 220]	Donner et al. (2011)
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, USA	1.0 × 1.0	2.5 × 2.0 [275 × 220]	Dunne et al. (2012)

GISS-E2-H	Goddard Institute for Space Studies, USA	2.5 × 2.0	2.5 × 2.0 [275 × 220]	Schmidt et al. (2014)
GISS-E2-R	Goddard Institute for Space Studies, USA	2.5 × 2.0	2.5 × 2.0 [275 × 220]	Schmidt et al. (2014)
IPSL-CM5A-MR	Institut Pierre-Simon Laplace, France	1.6 × 1.4	2.5 × 1.3 [275 × 145]	Dufresne et al. (2013)
MIROC5	Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, Japan Agency for Marine-Earth Science and Technology, Japan	1.6 × 1.4	1.4 × 1.4 [155 × 155]	Watanabe et al. (2010)
MIROC-ESM-CHEM	Japan Agency for Marin-Earth Science and Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental	1.4 × 0.9	2.8 × 2.8 [310 × 310]	Watanabe et al. (2011)
MIROC-ESM	Japan Agency for Marin-Earth Science and Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental	1.4 × 0.9	2.8 × 2.8 [310 × 310]	Watanabe et al. (2011)
MRI-CGCM3	Meteorological Research Institute,	1.0 × 0.5	1.1 × 1.1 [120 × 120]	Yukimoto et al. (2012)

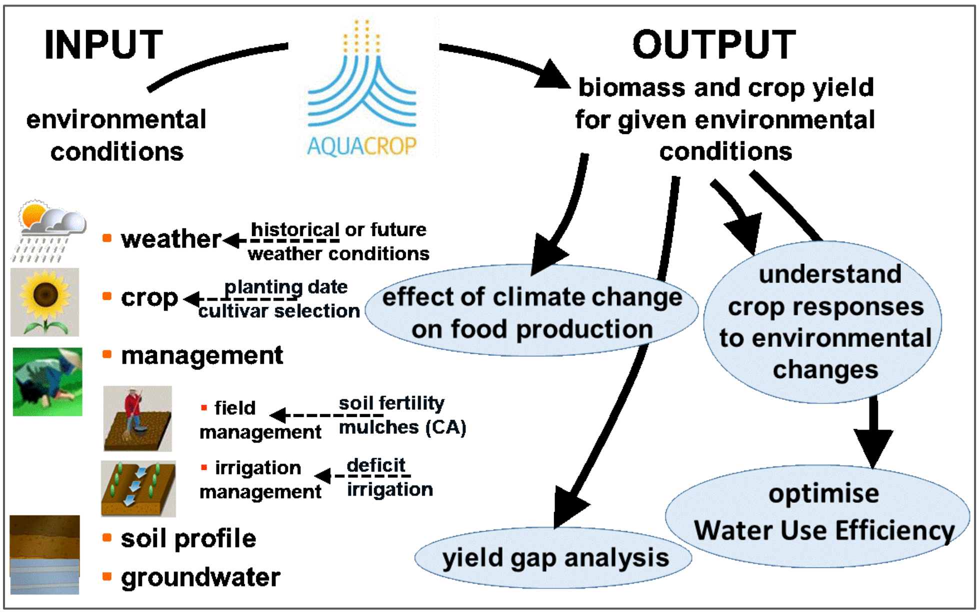
	Japan			
NorESM1-M	Norwegian Climate Centre, Norway	1.1 × 0.6	2.5 × 1.9 [275 × 210]	Bentsen et al. (2013)

Source: National Center for Atmospheric Research (NCAR), Research Applications Laboratory

Appendix B. Description of AquaCrop model used for prediction of yield and productivity under water-stress conditions

AquaCrop (http://www.fao.org/nr/water/aquacrop.html) is a crop water productivity model developed by the Land and Water Division of FAO. It simulates yield response to water of various crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. AquaCrop uses a relatively small number of explicit and mostly-intuitive parameters and input variables requiring simple methods for their determination. It includes the following sub-model components: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and CO_2 concentration; and the management, with its major agronomic practice such as irrigation and fertilization. Required model inputs include daily or monthly weather data (minimum and maximum temperature, and precipitation), soil properties, initial soil water content, cultivar characteristics, planting density, and dates of planting. AquaCrop is a user-friendly tool that can be used as a planning tool or to assist in assessing management decisions for both irrigated and rain-fed agriculture. AquaCrop is particularly useful for predicting crop production under different water-management conditions (including rain fed and supplementary, deficit and full irrigation) and investigating different management strategies (e.g. adjusting planting date, cultivar selection, fertilization management, use of mulches, rain water harvesting), under present and future climate change conditions. Figure B1 shows some practical applications of AquaCrop.

Figure B1: Some practical applications of AquaCrop



Appendix C. List of key informants and their affiliations

NAME	TITLE	INSTITUTION
Dr Cosmos Magorokosho	Senior Breeder	CIMMYT, Harare
Dr James Gethi	Seed Scientist	CIMMYT, Harare
Ms Sakhile Kudita	Genebank Manager	ICRISAT, Matopos
Dr Charles Mutimaamba	Head	Crop Breeding Institute, DR&SS
Mr Andrew Henderson	Breeder	Klein Karoo, Harare
Dr E. Havazvidi	Senior Breeder	SeedCo, Harare
Dr T. Matekaire	Senior Breeder	ZTS-SIRDC, Harare
Ms Nakai Matongera	Maize Breeder	Crop Breeding Institute, Harare
Mr Mark Mare	Small Grain Breeder	Crop Breeding Institute, Matopos
Dr X. Mhike	Senior Breeder	Pioneer, Harare
Mr D. Mangemba	Manager	Sandbrite Seeds, Harare
Mr Farai Zvavamwe	Production Manager	SeedCo, Harare
Dr K. Mazvimavi	Country Director	ICRISAT, Matopos
Mr O. Chipfunde	Acting Head	Genetic Resources and Biotechnology Institute, Harare

Appendix D. Precipitation and temperature in Zimbabwe - present and predicted future

Figure D1. Temperature in Zimbabwe - present and predicted future (2050s)

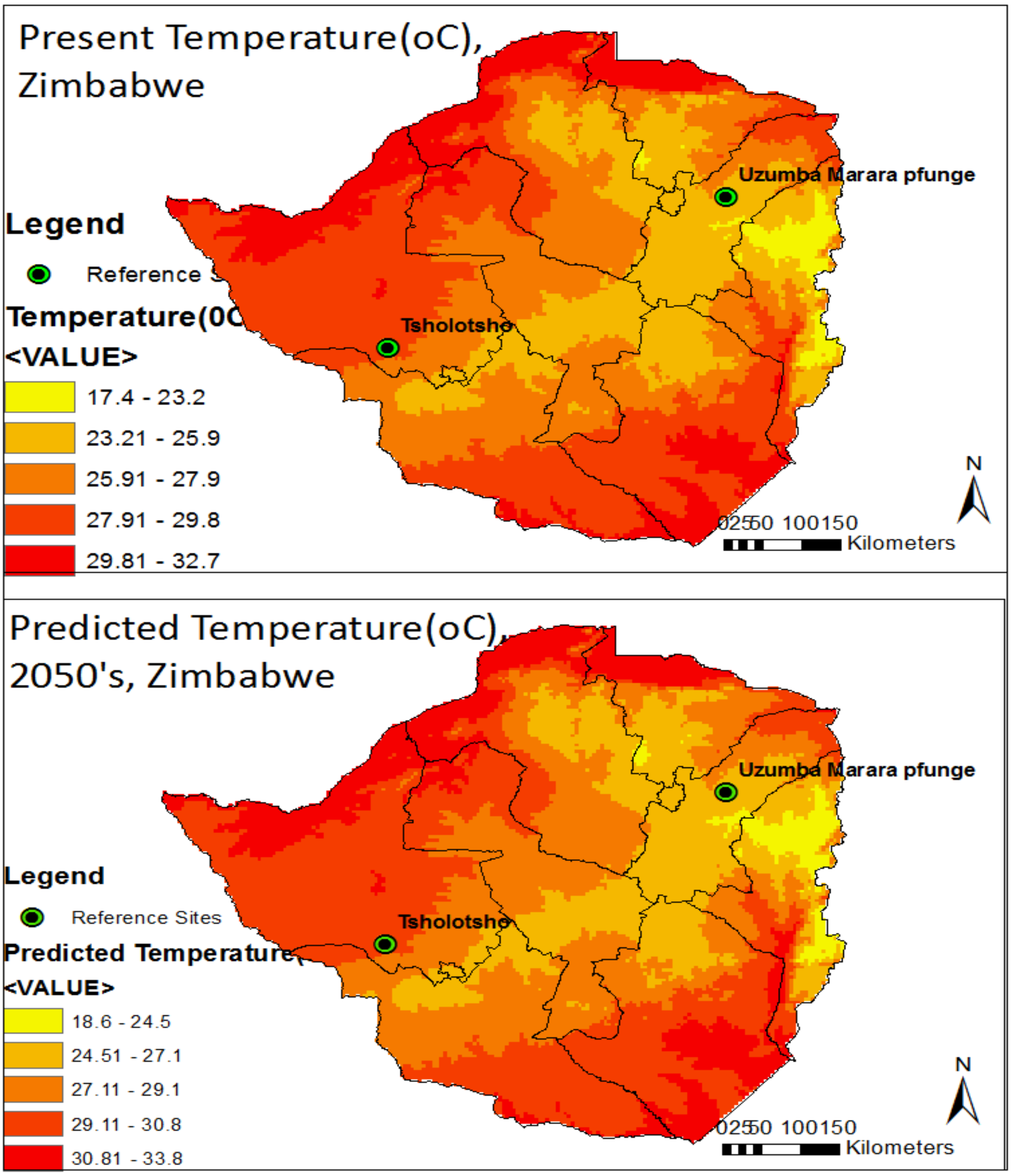


Figure D2. Precipitation in Zimbabwe - present and predicted future (2050s)

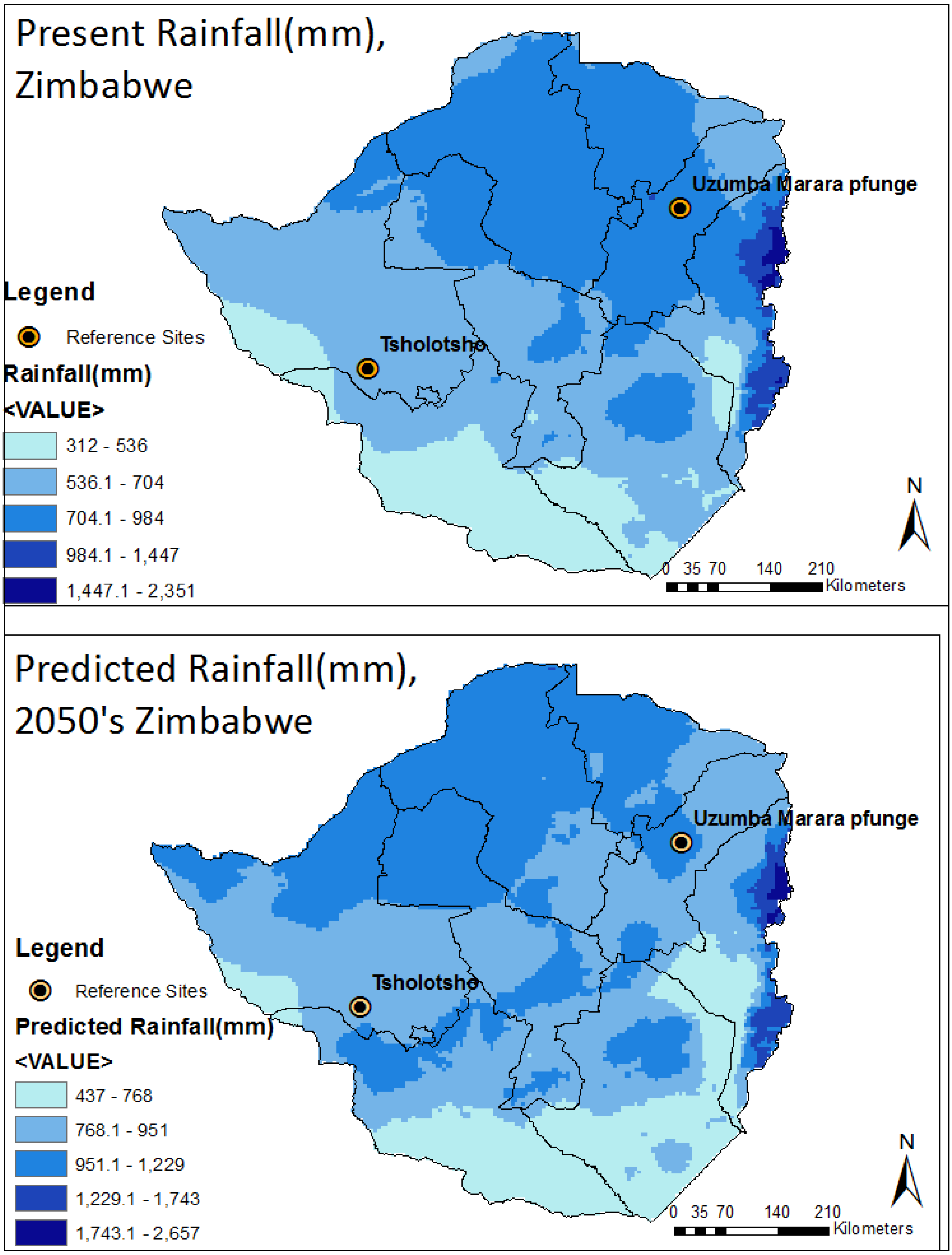


Table D1. Bioclimatic variables for UMP in Zimbabwe (present and predicted)

Bioclimatic variables for UMP at present	
Bioclimatic Variable	**Value**
Annual Mean Temperature [1]	21.0
Mean Monthly Temperature Range [2]	14.2
Isothermality (2/7) (* 100) [3]	58.9
Temperature Seasonality (STD * 100) [4]	318.5
Max Temperature of Warmest Month [5]	31.4
Min Temperature of Coldest Month [6]	7.3
Temperature Annual Range (5-6) [7]	24.1
Mean Temperature of Wettest Quarter [8]	23.8
Mean Temperature of Driest Quarter [9]	16.6
Mean Temperature of Warmest Quarter [10]	24.0
Mean Temperature of Coldest Quarter [11]	16.6
Annual Precipitation [12]	659
Precipitation of Wettest Month [13]	194
Precipitation of Driest Month [14]	0
Precipitation Seasonality (CV) [15]	124.8
Precipitation of Wettest Quarter [16]	478
Precipitation of Driest Quarter [17]	5
Precipitation of Warmest Quarter [18]	400
Precipitation of Coldest Quarter [19]	5

Bioclimatic Variables for UMP in 2050's	
Bioclimatic Variable	**Value**
Annual Mean Temperature [1]	22.4
Mean Monthly Temperature Range [2]	15.0
Isothermality (2/7) (* 100) [3]	54.6
Temperature Seasonality (STD * 100) [4]	338.5
Max Temperature of Warmest Month [5]	35.3
Min Temperature of Coldest Month [6]	7.9
Temperature Annual Range (5-6) [7]	27.4
Mean Temperature of Wettest Quarter [8]	23.5
Mean Temperature of Driest Quarter [9]	18.0
Mean Temperature of Warmest Quarter [10]	26.3
Mean Temperature of Coldest Quarter [11]	18.0
Annual Precipitation [12]	859
Precipitation of Wettest Month [13]	200
Precipitation of Driest Month [14]	0
Precipitation Seasonality (CV) [15]	122.1
Precipitation of Wettest Quarter [16]	577
Precipitation of Driest Quarter [17]	1
Precipitation of Warmest Quarter [18]	253
Precipitation of Coldest Quarter [19]	4

Table D2. Bioclimatic variables for Tsholotsho in Zimbabwe (present and predicted)

Present Values for Bioclimatic Variables in Tsholotsho

Bioclimatic Variable	**Value**
Annual Mean Temperature [1]	20.8
Mean Monthly Temperature Range [2]	15.5
Isothermality (2/7) (* 100) [3]	58.6
Temperature Seasonality (STD * 100) [4]	347.0
Max Temperature of Warmest Month [5]	32.5
Min Temperature of Coldest Month [6]	6.0
Temperature Annual Range (5-6) [7]	26.5
Mean Temperature of Wettest Quarter [8]	23.4
Mean Temperature of Driest Quarter [9]	16.0
Mean Temperature of Warmest Quarter [10]	24.0
Mean Temperature of Coldest Quarter [11]	15.9
Annual Precipitation [12]	573
Precipitation of Wettest Month [13]	132
Precipitation of Driest Month [14]	0
Precipitation Seasonality (CV) [15]	107.6
Precipitation of Wettest Quarter [16]	366
Precipitation of Driest Quarter [17]	3
Precipitation of Warmest Quarter [18]	229
Precipitation of Coldest Quarter [19]	7

Predicted values for bioclimatic variables in Tsholotsho (2050s)

Bioclimatic Variable	**Value**
Annual Mean Temperature [1]	22.2
Mean Monthly Temperature Range [2]	14.8
Isothermality (2/7) (* 100) [3]	54.6
Temperature Seasonality (STD * 100) [4]	336.1
Max Temperature of Warmest Month [5]	35.1
Min Temperature of Coldest Month [6]	7.9
Temperature Annual Range (5-6) [7]	27.2
Mean Temperature of Wettest Quarter [8]	23.3
Mean Temperature of Driest Quarter [9]	17.8
Mean Temperature of Warmest Quarter [10]	26.1
Mean Temperature of Coldest Quarter [11]	17.8
Annual Precipitation [12]	878
Precipitation of Wettest Month [13]	204
Precipitation of Driest Month [14]	0
Precipitation Seasonality (CV) [15]	122.2
Precipitation of Wettest Quarter [16]	592
Precipitation of Driest Quarter [17]	1
Precipitation of Warmest Quarter [18]	256
Precipitation of Coldest Quarter [19]	5