Evaluating Climate Change Adaptation Strategies for Disaster Risk Management: Case Study for Bethlehem Wheat Farmers, South Africa

By

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DECLARATION

I, ***Kgadiko Lucas Serage***, hereby declare that this work submitted for assessment is my own work, unaided, except where I have indicated otherwise. All sources referred to are acknowledged adequately in the text and in the list. I accept the rules of assessment of the University of the Free State.

Signed. …………………………… Date………………………..

Kgadiko Lucas Serage

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- Above them all, I thank the ALLMIGHTY GOD for HIS everlasting love and protection.

DEDICATTION

I dedicate this research work to
my beloved wife, Wendy, who has made all my efforts worthwhile.

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ACROMYNS

BFPA	Bethlehem Fire Protection Association
CIMMYT	International Maize and Wheat Improvement Center
DAFF	Department of Agriculture, Forestry and Fisheries
DRM	Disaster Risk Management
DSSAT	Decision Support System in Agricultural Technology
EU	European Union
FSB	Financial Services Board
GCM	General Circulation Model, also called Global Circulation Model
IPCC	Intergovernmental Panel on Climate Change
NAC	National Agro-meteorological Committee
NCCC	National Committee on Climate Change
NDMC	National Disaster Management Centre
PDAs	Provincial Departments of Agriculture
SADC	Southern African Development Community
SAWS	South African Weather Services
SRES	Special Report on Emissions Scenarios
UNCSDR	United Nations Corporate Strategy for Disaster Reduction
UNFCCC	United Nations Framework Convention on Climate Change

ABSTRACT

The most important Agro-climate factors of primary agricultural production are temperature and rainfall. The impact of climate change is seen the best in the agricultural industry.

The vulnerability of agriculture to climate change has become an important issue because of reduced crop productivity that is experienced by farmers. Wheat is the second staple crop in South Africa, maize is the first. The main dryland winter wheat production in South Africa is in the Free State province, in the areas surrounding Bethlehem. This study was carried out in Bethlehem. The objectives are to review the Disaster Risk Management framework in South Africa and its role in agriculture and the sustainability of food security, to explore the perception that commercial farmers have on climate change and how it influences their wheat production, to evaluate the adaption options open to commercial farmers, and to assess the impact that these adaptation options have on climate change and wheat crops by using the crop simulation model DSSAT.

This study established that South African Policy and the legislative framework on Disaster Risk Management is well in existence and articulated to address the vulnerability of food security because of climate change and any form of disaster. The South African national legislative framework and strategies for disaster risk reduction appear to be in cohesion with the regional strategies. 97.1% of the sampled farmers perceive that there has been some change in the climate, 2.9% of the farmers were not sure whether there was a change or not. The farmers perceive climate change by observing that there is an increase in temperature and there are alterations in temperature ranges (average minimum and maximum temperatures) and there is an alteration in temporal variations. The farmers' observations are that there is an alteration in the rainfall pattern, particularly a reduction in the rainfall amount received per year. On mitigation measures, the three most common internal farming adaptation measures indicated by the sampled wheat farmers in Bethlehem are: changing the planting time (23.6%), changing the crop (22%), and changing the cultivars (15.7%).

The result indicated that changing the cultivars, changing the planting date and to have better fertilizer level management are some of the favorite adaptation measures the farmers use to mitigate crop yield losses due to climate change. The model shows all three cultivars performing better on later planting dates than earlier planting dates. Elands performed higher than all the other cultivars under all the fertilizer management levels. The highest grain yield was 3.4 t ha^{-1} for Eland. SST 124 and Betta DN were 1.5 and 1.4 tha^{-1} respectively under higher fertilizer management levels (75kg Nha^{-1}). Elands performed higher under low fertilizer management levels (25kg Nha^{-1}) with a yield of 2.4 tha^{-1} followed by the 1.1 and 1.0 tha^{-1} of SST 124 and Betta-DN respectively. Late planting combined with medium fertilizer levels (50kg Nha^{-1}) surpassed the early planting combined with 75kg Nha^{-1} in yield by 32%, 26% and 17% for Elands, SST 124 and Betta-DN respectively.

Changing to cultivars such as Elands, combined with late planting dates and a medium level of fertilizer management, is suggested as a solution to mitigate yield loss due to climate change, where a yield of 2.5 t ha^{-1} is a 70% probability. Changing cultivars, planting dates and fertilizer levels may be one of the strategies that can be adopted towards mitigating the risk of crop losses and thus improving food security. Such measures should be supported in terms of research resources and training.

Key words: *Dryland wheat, climate change, Disaster risk management, adaptation & mitigation measures, Decision support tool*

CHAPTER 1

INTRODUCTION

1.1 Background and Rationale

Climate change poses a variety of disaster risks to communities and affects all abiotic and biotic systems upon which human life depends. The irony is, in the quest for a rather decent life, human activities emitted gases that induced climate change (IPCC, 2007). There is an urgent need to adapt to climate change in mitigation to the variety of risks it poses to human life. Agriculture is the industry most affected by the impact of climate change. People experience a rise in temperature and a change in rainfall patterns that is characterized by the hostile climatic conditions such as severe thunderstorms, low and erratic seasonal rainfall (IPCC, 2007). Agro-climatic factors, mainly temperature and rainfall, are the most important factors that influence primary agricultural production, minimal changes in temperature and rainfall result in significant changes in production levels of crops.

The increase in temperatures and erratic rainfall patterns can lead to either floods or drought risks. Climate change is predicted to have serious implications on food production if appropriate adaptation measures and mitigation are not implemented (Beletse, et al., 2014; Howden, et al., 2007). This affects food security negatively. Studies have shown that developing countries are the most vulnerable to climate change and the effect thereof (Amadou, et al., 2015; Apata, 2011; Gadédjisso-Tossou, 2015). This may have serious implications to vulnerable households and communities, particularly in rural areas. Climate change causes about two-thirds of the disasters associated with crops. It is evident that the link between climate change and disaster risk is growing (Gadédjisso-Tossou, 2015). Countries facing high levels of disaster risks are mainly the under developed countries (DFID Department of International Development, n.d.). According to the (FAO, n.d.) three out of four people in developing countries live in rural areas and are highly dependent on agriculture for their livelihoods. Disasters tend to have the most severe consequences on poor, vulnerable and agriculture based populations.

Agriculture in most Sub-Saharan African countries is crucial for local livelihood and the primary contribution to the national GDP and remains the main base of food security in those regions (Chuku & Okoye, 2009). And yet, according to Ramirez-Villegas et al. (n.d.), Southern African countries are among the Sub-Saharan African countries where it is predicted that climate change is going to impose a negative impact on grain production by the 2030's. In South Africa statistical evidence suggests that South Africa has been getting hotter over the past four decades. Kruger and Shongwe (2004) analyzed climate data from 26 weather stations across the country and reported the following: Of the 26 weather stations, 23 showed that the average annual maximum temperature had increased, in 13 of them significantly. Average annual minimum temperatures also showed an increase, of which 18 were significant. In general, their analysis indicate that the country's average yearly temperatures increased by 0.13°C per decade between 1960 and 2003, with varying increases across the seasons: Fall 0.21°C, Winter 0.13°C, Spring 0.08°C and Summer 0.12°C (Kruger & Shongwe, 2004). There was also evidence of an increase in the number of warmer days and a decrease in the number of cooler days.

South Africa has two main farming seasons given the temperatures and rainfall patterns, this being the summer season from October/November to March/April and the winter season from April/May to August/September (Benhin, 2006). Wheat is produced during the winter season. The dry land wheat production is highly challenged by the effects of climate change. Wheat, after maize, forms the most important crop and is basically considered to be the staple food of the people of South Africa. Wheat farming is said to be one of the most essential activities in South Africa and is being planted on a massive scale. The Free State Province in South Africa is known as the largest producer of wheat in the country, it contributes about 45% of the country's wheat (ARC-SGI, 2009). The other producing areas in South Africa include the Western Cape, Northern Cape and Mpumalanga (ARC-SGI, 2009). However, it seems like the recent South African drought, which led to a change and a decline in wheat production, has shifted the Free State from being the largest producer of wheat in South Africa to second place, short-term view.

The intention of the study is to integrate the provisions / knowledge of the existing Disaster Risk Management framework into the wheat production and to examine the farmers' perceptions of the concept of climate change. The study is supported by assessing the improved alternative management practices (such as planting time, cultivars, and fertilization) as climate change adaptation strategies for commercial wheat farmers in the Bethlehem region in South Africa. The preliminary results contribute to the policy structures that are highlighted by the Disaster Risk Management in relation to agriculture and food security in South Africa. The study also intends to review the policy structures that the Disaster Risk Management has available in relation to agriculture, food security and crop production in South Africa.

1.2 Problem statement

In winter crops, such as wheat, the onset of rainfall and subsequent rainfall amounts in the season, presents a challenge with double standards:

Firstly, the amount of soil moisture, during planting in winter, depends on a rainfall amount and distribution during the previous rainy season (summer), soil type and soil management practices. In delayed planting, the farmers mainly wait for the temperatures to drop to support germination and vernalisation. Planting is also delayed to ensure that the crop anthesis and grain formation coincide with rising temperatures to avoid cold or frost damage. However, the farmers cannot wait too long because the stored soil moisture will be lost and this will result in poor germination. Waiting also influences the required seeding rate.

Secondly, wheat production also relies on the onset of rainfall in the next rainy season (summer). The critical stages of crop development (flowering and grain filling) need to coincide with this rainfall onset for optimum yield. This makes the planting date and cultivar choice an important management factor for rainfed winter wheat production.

Climate and crop management risk challenges in wheat production can be assessed by integrating a crop growth model through simulating yield variations. Crop model simulations are cheaper, and a more suitable tool, to estimate future climate risks and is used to test appropriate adaptation measures (Abayisenga, 2015; Attri & Rathore, 2003). Climate change makes it more difficult for crop producers to manage an already challenging environment. In addition, there is a lack of consideration for the commercial farmers' capacity to manage climate risks that requires adequate national institutions and policy frame works in Disaster Risk Management. This study incorporates the farmer's perceptions on climate risk management, and how they perceive existing institutional and policy arrangements for climate change adaptation and disaster risk reduction strategies, as these factors threaten future food security. An attempt to establish a mitigation solution, using a range of adaptation strategies to avoid and minimize the negative impact of climate change on commercial wheat production, is of paramount importance. Hence, a case study in the Bethlehem area for commercial wheat production was conducted with the following aims and objectives.

1.3 Aim of the study

The overall aim of this study is to integrate the provisions and knowledge of the existing Disaster Risk Management framework into commercial wheat production and to assess the farmers' perceptions of the concept of climate change. This study also aims to evaluate improved management practices (such as planting time, cultivars, and fertilization) as a climate change adaptation strategy for commercial wheat farmers in the Bethlehem region in South Africa.

Specific objectives of the study:

- To review the Disaster Risk Management framework in South Africa and its prominent address to wheat production risks in the Bethlehem region in relation to the vulnerability to climate change.
- To explore the commercial wheat farmers' perceptions of climate change and the effect it has on wheat production, and their perceptions of the adaptation strategies commonly practiced.

- To assess different management options (such as planting time, improved cultivars, and fertilization rates) as climate change adaptation measures for better wheat yields, using a crop growth model (DSSAT).
- To develop preliminary recommendations as an agricultural support system for commercial wheat farmers, to assist in mitigating the effects of climate change on wheat yield.

1.4 Limitations of this study

This study does not intend to investigate the factors determining the adoption of some farming practices. This study does not intend to determine the efficiency and the implementation capacity of the policies and institutional framework as determined by the Disaster Risk Management. The entirety of the disaster continuum is not addressed, but it rather focuses on mitigation strategies. The study's main interest is in the use of crop simulation models to assess farming practices adapted by farmers as measures to mitigate the impact of climate change, and to demonstrate the model's application as a decisive tool in mitigation of climate change through integrating existing Disaster Risk Management frameworks. There were difficulties in obtaining the crop co-efficient for some of the cultivars mentioned by the farmers in the survey. The crop model was calibrated using cultivars whose co-efficient were readily available.

1.5 Outline of chapters

The overall aim and objectives of this study were presented in this chapter, **Chapter 1**. **Chapter 2** deals with the literature review. The reviewed literature entails the disaster management concept, the continuum and the South African legislative framework. Literature on climate change was reviewed, its impact on agriculture, basic food prices and food security in South Africa was determined. The impact of agriculture on the climate was equally reviewed. Previous adaptation studies used by farmers were reviewed. The review looked into crop simulation models and their use in different countries together with climate change scenarios. The chapter ends with a conclusion. **Chapter 3** describes the background of the study area. A description is given of the population and demography, climate, soils as well as agriculture and economic activities. The methods and models applied in this study are also explained in this chapter. **Chapter 4** presents the results of this study. The chapter describes how legislative framework addresses crop production in disaster management. It presents the descriptive analysis of the survey data. The results of crop simulations are presented and discussed in this chapter, and the chapter ends with preliminary recommendations for agricultural support in the case of climate change. It also mentions other tools that can be used for further research. **Chapter 5** contains a summary and the general recommendations of this study.

CHAPTER 2

LITTERATURE REVIEW

2.1 Introduction

Climate change can be a rather wide subject to study. It has been narrowed down to drought, influenced by low and erratic rainfall in semi-arid areas. Drought itself can be a daunting subject to study in crop production systems, hence the study was narrowed down to focus on agricultural drought. Agricultural drought is described as linked to a specific time in the crop stage, development and yield factors of a cultivar. The farmers' perceptions and adaptations to climate change will be the subject of the literature review, and how their perceptions relate to crop failure conditions during droughts. This literature review will juxtapose between climate change, the wider concept, and drought, the narrow concept. This chapter will also deal with a review of related literature on Disaster Risk Management, which is also a wide subject. This is narrowed down to the South African Policy and legislative framework on disaster management, mitigation in the disaster continuum. The literature review will also include studies on agricultural production measures that mitigate the impact of disasters induced by climate change. Crop simulation models are also reviewed and lastly a conclusion on the reviewed literature is presented.

2.2 Conceptual framework of drought – food insecurity

To avoid misconceptions and misinterpretations of this chapter, and probably of the subsequent results of this study, a conceptual framework is hereby presented to bring the concept of climate change, drought, agricultural drought, poor crop productivity and food insecurity into context (Figure 2.1). Nelson, et al. (2009) emphasised that climate change impacts on agriculture and human well being, this includes the effects it has on crop production (quality and quantity), food prices and consumption. Furthermore, climate change affects economic systems, as farmers and other related industry participants adjust their operations in order to adapt to climate change.

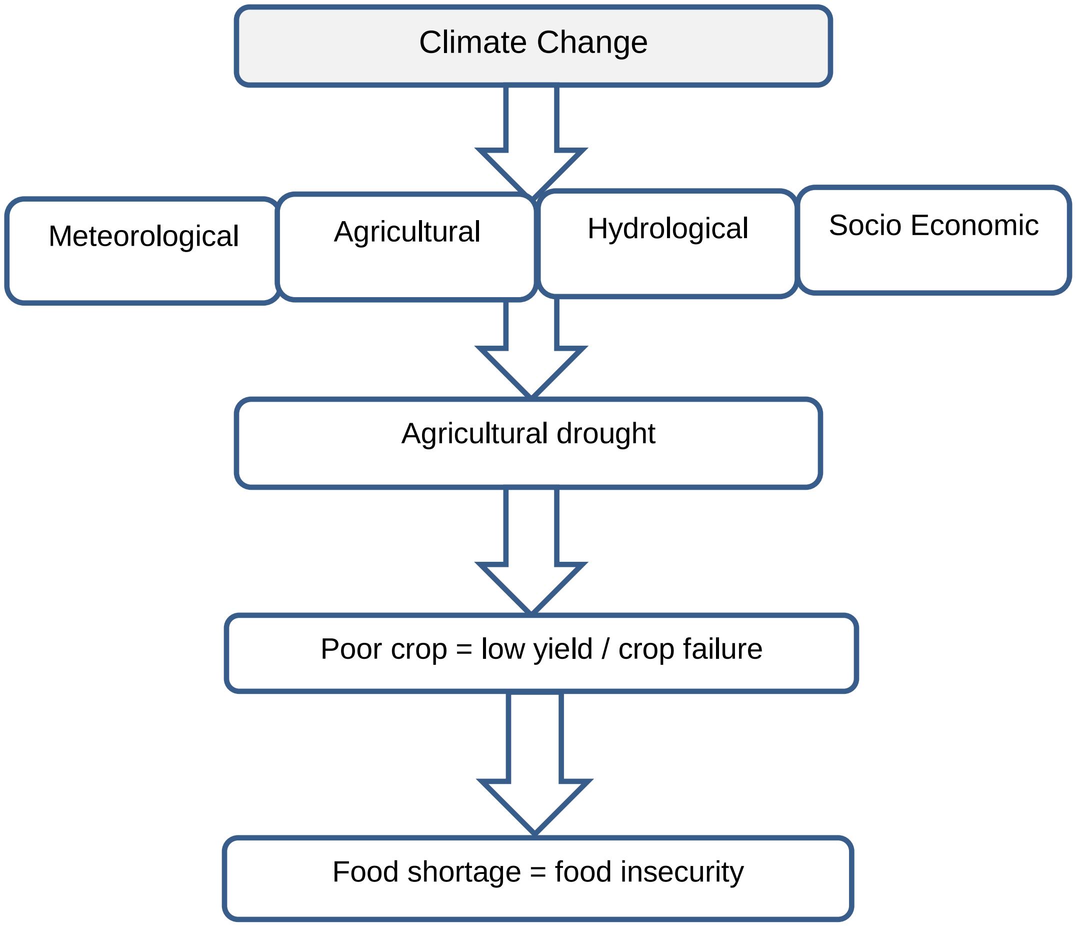


Figure 2.1. Illustration of the impact pathways of Climate change – Drought – Food Insecurity

2.3 Disaster risk management

Countries in tropical and subtropical latitudes will experience more water related disasters as the likelihood of human induced climate change increases. For example, non-sustainable overuse of resources causes pollution and ultimate changes in the environment. The local changes in temperature and rainfall affect the environment through accelerated desertification, land degradation, and overall agricultural output. The intensity and frequency of such extreme hydro meteorological events are the effect of climate change, this is according to the United Nations Corporate Strategy for Disaster Reduction (n.d.).

> *'DFID Department for International Development, (n.d.) describes what makes a disaster in this manner. Disasters have two causes being: the degree of exposure (of people, infrastructure or economic activities) to physical events or*

hazards, and the vulnerability of the exposed things to the hazard or shock. Meaning that the potential for a hazard to become a disaster depends on the population's vulnerability or coping capacity. The more vulnerable are the worst affected. The level of vulnerability depends on the level of access to resources and services that can be used, or to generate alternative coping options. Vulnerability also relates to the extent to which the population is exposed to risk'.

Disasters can be triggers for food insecurity. It is reported that 20 million people in Africa are relying on relief to meet their basic food needs. The governments and the international community treat the situation by providing humanitarian relief, which is a short term-solution. Disaster risk reduction should aim at dealing with elements such as, vulnerability, hazards, and exposure. Reducing vulnerability also build resilience (DFID Department of International Development, n.d.).

Literature reports that international commitments to disaster risk reduction were made at the World Conference on Disaster Reduction. The G8 countries committed themselves to incorporate the disaster management issue effectively into their development policy and planning. The importance of disaster management was also referred to by The Millennium Review Summit Declaration. An additional commitment was made by the G8 countries to the European Union in Action Plan on Climate Change (DFID Department of International Development, n.d.; World Conference on Disaster Reduction, 2005).

In South Africa, prevention and mitigation of disaster is advocated by the Disaster Management Act 57 of 2002 sections 20, 33, and 47, to be elaborated on in the later sub-section (Section 2.3.2). In disaster management science and technology is hailed for its important role in monitoring hazards and vulnerabilities. Science and technology also play an important role in developing tools and methodologies for disaster risk reduction (UN/ISDR, 2002). Crop farmers need to use the disaster risk reduction approach in their farming practices, together with scientific and technological advancements to overcome the challenges of climate change. To achieve that farmers need scientific guidance and policy guidance.

2.3.1 Disaster management continuum

Disaster management is a cycle that consists of the following stages:

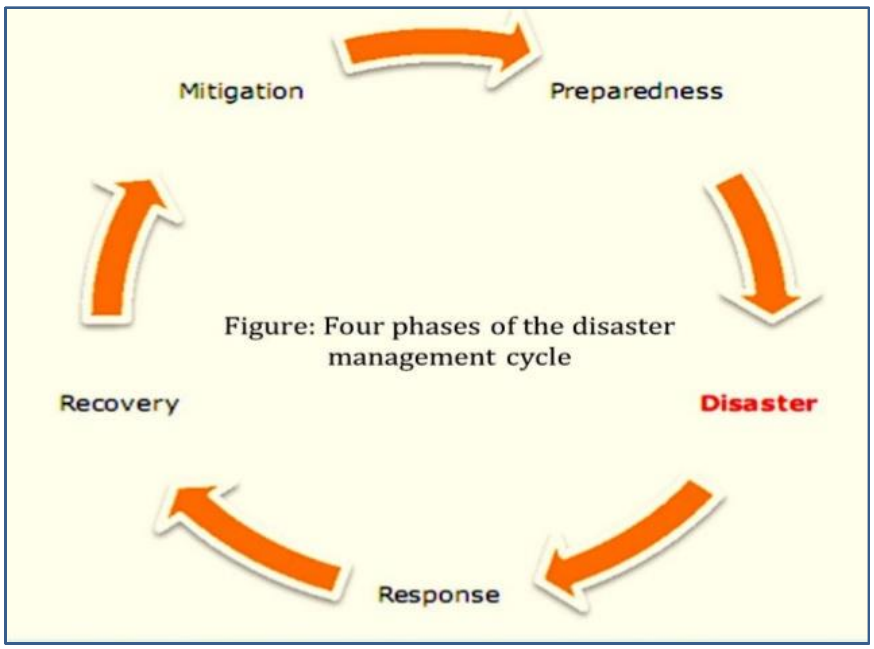
Risk assessment: Diagnostic process to identify the risks that a community faces.

Mitigation: Measures that prevent or reduce the impact of disasters.

Preparedness: Planning, training, & educational activities for things that can't be mitigated.

Response: The immediate aftermath of a disaster, when business is not as usual.

Recovery: The long-term aftermath of a disaster, when restoration efforts are implemented in addition to regular services (Baas, et al., 2008).



(Source: https://image.slidesharecdn.com)

Figure 2.2 Phases of disaster management continuum (Baas, et al., 2008)

2.3.2 South African Policy and legislative framework on disaster risk management

The *Disaster Management Act 57 of 2002* requires the formation of a policy framework for disaster management and that was published in South Africa in 2005. The policy, documented as *National Disaster Management Framework of 2005*, was published. In order to comply with the Disaster Management Act 57 of 2002 and the National Disaster Management Framework of 2005, the Department of Agriculture, Forestry and Fisheries (DAFF) has formed a structure for *Climate Change and Disaster Management Directorate.* This directorate serves to co-ordinate Disaster Risk Management functions within the sector. It is not the objective of this study to detail these legislative frameworks but only to highlight the role and functionality. In a presentation for the portfolio committee in October 2002, DAFF highlighted the important policy developments and implementation strategy which has a bearing on this study. The link to this study is the policy framework that deals with crop producers (farmers) that require the intervention of research and technological advancement to produce better crops, and the policy framework to mitigate the impact of climate change on food security. The following policy development committees regarding the implementation of Risk Management has a link to this study:

- *National Agro-meteorological Committee (NAC)* – The NAC assists DAFF with the implementation of an early warning system in support of Disaster Risk Management. This committee is chaired by the DAFF and constitutes of the South African Weather Service, Agricultural Research Council, Provincial Departments and several Universities.
- *National Drought Task Team* – A technical committee addressing drought issues in the country. The committee is chaired by the DAFF (secretariat) and other participants include: PDA's, NDMC, Organised agriculture, the Department of Social Development, Rural Development and Land Reform, and Water Affairs.
- *National Committee on Climate Change (NCCC)* – Consultation of climate change stakeholders to give an input on technical climate change issues. The DAFF constitutes this committee to learn lessons and share information from research experts in the committee.

Section 4 of the *South African Weather Service Amendment Act No.48 of 2013* refers to the South African Weather Services (SAWS) as a long-term custodian of a reliable national climatological and ambient air quality record. The long-term climate records and any other climate records are required in crop models that are used to predict crop yields and to model crop management options (South African Weather Service Amendment Act, 2013). *National Water Act No. 36 of 1998*, Section 137 subsection 2 sub-subsection (g) mentions the establishment of a national monitoring system on water resources to assess, among other things, the atmospheric conditions which may influence water resources (National Water Act, 1998).

Section 145, subsection 1 and 2 advises on the establishment of a warning system in relation to events listed (drought is among them).
It is evident that there is a link between Section 4 of the South African Weather Services Amendment Act No 48 of 2013 and Section 137 and Section 145 of the National Water Act No. 36 of 1998. For proper monitoring reliable climatic data should be obtained.

For further interrogation of these policy strategies, readers are also referred to the following documents, (DAFF, 2002(a); DAFF, 2005; DAFF, 2002(b)). The African Regional Strategy for Disaster Risk Reduction was adopted by African ministers at the 10th meeting of the African Ministerial Conference on the Environment in June 2004. This emerged during the development of NEPAD’s operational programs with the aim to address gaps in the following areas: institutional frameworks, risk identification, knowledge management, governance and emergency response. UN/ISDR (2002); NEPAD (2004) expanded on the regional co-operation, interactions and experience in disaster risk reduction.

Bringing all this together in this current study, a Monitoring system and Warning system will be used as a tool to reduce vulnerability and exposure to drought. If well implemented, this will have a positive effect on crop farmers, who need such a warning system. Again, the legislation indicates the strategy for disaster risk reduction by the Government of the Republic of South Africa. The historical timeline and background of the emergence of this strategy is documented in UN/ISDR (2002) chapter 3.

2.4 Climate Change

2.4.1 What is climate change?

The definition of climate change is given by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC). The two definitions are relevant for this study and are taken as the official definitions (ISDR, 2008).

Climate change is defined by IPCC (2007) as 'a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer'. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

UNFCCC defines climate change as 'the climate change that can be attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods' (ISDR, 2008).

Climate describes the overall long term characteristics of weather experienced at a place. On the other hand, weather is a set of meteorological conditions, temperature, rain, sunshine, wind etc., at a particular time and place (ISDR, 2008). Climate change manifests itself clearly and consistently, year after year, where changes in weather patterns is observed. In some areas climate change manifests itself in a disruptive way that may be difficult to manage, as it becomes increasingly unpredictable with the variability of weather patterns increasing (Cattaneo, et al., 2012).

In South Africa increases in average annual temperatures and decreases in average annual precipitation has been observed from 1970 to 1990. There is a seasonal variability in precipitation patterns across the country's regions. South Africa has an increasing trend in the number of hot days and nights and also an increase in the number of extreme daily temperatures (UNICEF, 2011; Kruger & Shongwe, 2004). Blignaut, et al. (2009) has reported that the temperature has increased in all the provinces accept one, (Mpumalanga), and rainfall reduced in all the provinces accept one, (the Western Cape), during the periods stated in Table 2.1.

Table 2.1 South African regions temperature and rainfall and percentage change between 1970 – 1979 and 1997 – 2006

Mean annual rainfall by region	Mean annual temperature by region	% change in rainfall	% change in temperature
<550 mm			
- Northern Cape	>25^{0}C	-21.4	1.7
- North West	>25^{0}C	-11.3	2.3
550 – 700 mm			
- Western Cape	24.5 – 25 ^{0}C	0.3	1.5
- Free State	24.5 – 25 ^{0}C	-3.5	1.7
- Limpopo	>25^{0}C	-1.4	3.8
- Eastern Cape	<25.5^{0}C	-4.8	2.8
>700 mm			
- Gauteng	<25.5^{0}C	-7.1	4.0
- Mpumalanga	24.5 – 25 ^{0}C	-5.7	-2.1
- KwaZulu-Natal	<25.5^{0}C	-5.8	2.1

Extracted from Blignout, et al. (2009)

2.4.2 Impact of agriculture on climate change

Agricultural production contributes to climate change by releasing greenhouse gases (GHG) such as, Carbon dioxide, Nitrous oxides and Methane, in the main atmosphere. Under anaerobic soil conditions, when there is an excess of nitrogen not used, nitrous oxides are released. Carbon dioxide is released in the whole agro-production process through the pre-processing system, including the production and administration of production inputs such as fertilizers, crop protection chemicals and agricultural machinery (Haverkort & Hillier, 2011). According to Haverkort & Hillier (2011), using the Cool Farm Tool (CFT) model on potatoes, they found that the total and relative kg CO_2 costs of producing 1 ton of potatoes is 405.1 for table potatoes, 457.8 for organic potato production, 609.5 for seed poptatoes and 229.1 for starch potatoes.

Methane production in agriculture mostly originates from ruminant animals. Methane is produced in the rumen (multi-chambered stomach for ruminant animals) when microbial fermentation takes place. The process is called enteric fermentation. Methane is also produced under anaerobic decomposition of organic matter, a condition prevalent in rice production (Saulter, 2013; HLPE, 2012). Convertion of non-agricultural land to agricultural land influences emissions of methane and nixious oxides in the manner described above. Agricultural practices are expected to be alined to mitigation options to reduce contribution to climate change while maintaing food security.

2.4.3 Impact of climate change on food production

The impact of climate change on agriculture is a burning issue in all the agricultural sectors. Climate change influences crop and livestock production, input supplies, hydrological cycles and other components of the agricultural system. For example, the effect of a changing climate on agriculture is well reviewed in the document by Adams, et al. (1998) and many other poineer scientists that are highly concerned. All countries are affected by climate change, though poorer countries are more affected than their developed counterparts (ISDR, 2008; IPCC, 2007). Several studies in Southern Africa have been conducted on the potential effects of climate change on agricultural production (Benhin, 2006; Blignaut, et al., 2009; LTAS, n.d.; Nelson, et al., 2009).

In South Africa for instance, maize yield is projected to decrease by 9 to 18% by 2050, tested with a climate change scenario, while rice yield is projected to drop by 7 to 27% and wheat yield by 18 to 36% (Nelson, et al., 2009; Rosegrant, et al., 2013).Table 2.2, as an extract, reports the effects of climate change on crop production in 2050 compared to production without climate change, based on the CSIRO and NCAR scenarios, as reported by Nelson, et al. (2009). The effect on the rest of the globe is presented in Table 2.2 in Nelson, et al. (2009). According to Nelson, et al., (2009), the negative effects of climate change on crop production are especially pronounced in Sub-Saharan Africa and South Asia. In Sub-Saharan Africa, the yield decline of rice, wheat, and maize with climate change is15 %, 34 %, and 10 %, respectively.

Table 2.2 Climate change effects on crop production, no CO_2 fertilization

Region Production Area	Grain Crops	Years of Production			Climate change scenario	
		2000 (mmt)	2050 no climate change(mmt)	2050 no climate change(% Δ)	CSIRO (% Δ)	NCAR (% Δ)
North Africa & Middle East	Rice	5.5	10.3	87.4	- 32.9	- 39.7
	Wheat	23.6	62.0	162.3	- 15.1	- 8.7
	Maize	8.2	13.1	59.4	- 0.8	- 9.8
Sub-Saharan Africa	Rice	7.4	18.3	146.0	- 14.5	- 15.2
	Wheat	4.5	11.4	154.4	- 33.5	- 35.8
	Maize	37.1	53.9	45.3	- 9.6	- 7.3

Extracted from Nelson, et al. (2009)

- *The columns labeled "2050 No CC (% change)" indicate the percent change between production in 2000 and 2050 with no climate change.*
- *The columns labeled "CSIRO (%change)" and "NCAR (% change)" indicate the additional percent change in production in 2050 due to climate change relative to 2050 with no climate change.*
- *mmt = million metric tons.*

According to Rosegrant et al. (2013) the world population will reach a million by 2050. Food demand will be driven by the growing population and the growing income. More production of cereals, about 52%, will be needed between 2005 and 2050. The price of rice is expected to increase by 79%, maize by 104% and that of wheat by 88% between 2005 and 2050. At the same time the number of people vulnerable to hunger will increase to 1, 031 million. Food security is Africa's challenge and climate variability has a big influence on low food production in Africa. The following two sub-sections review wheat production trend and the perspective on food security.

2.4.4. South African wheat production trend and climate change

South African wheat production has been declining since 1998 as seen in Figure 2.3, mainly due to unfavorable weather conditions. The areas planted under wheat also declined since 2003, after showing some form of fluctuation until 1998. This decline in areas planted resulted in a decline in wheat production in the country (USDA, 2017). Wheat imports are on the rise to satisfy the ever increasing consumption.

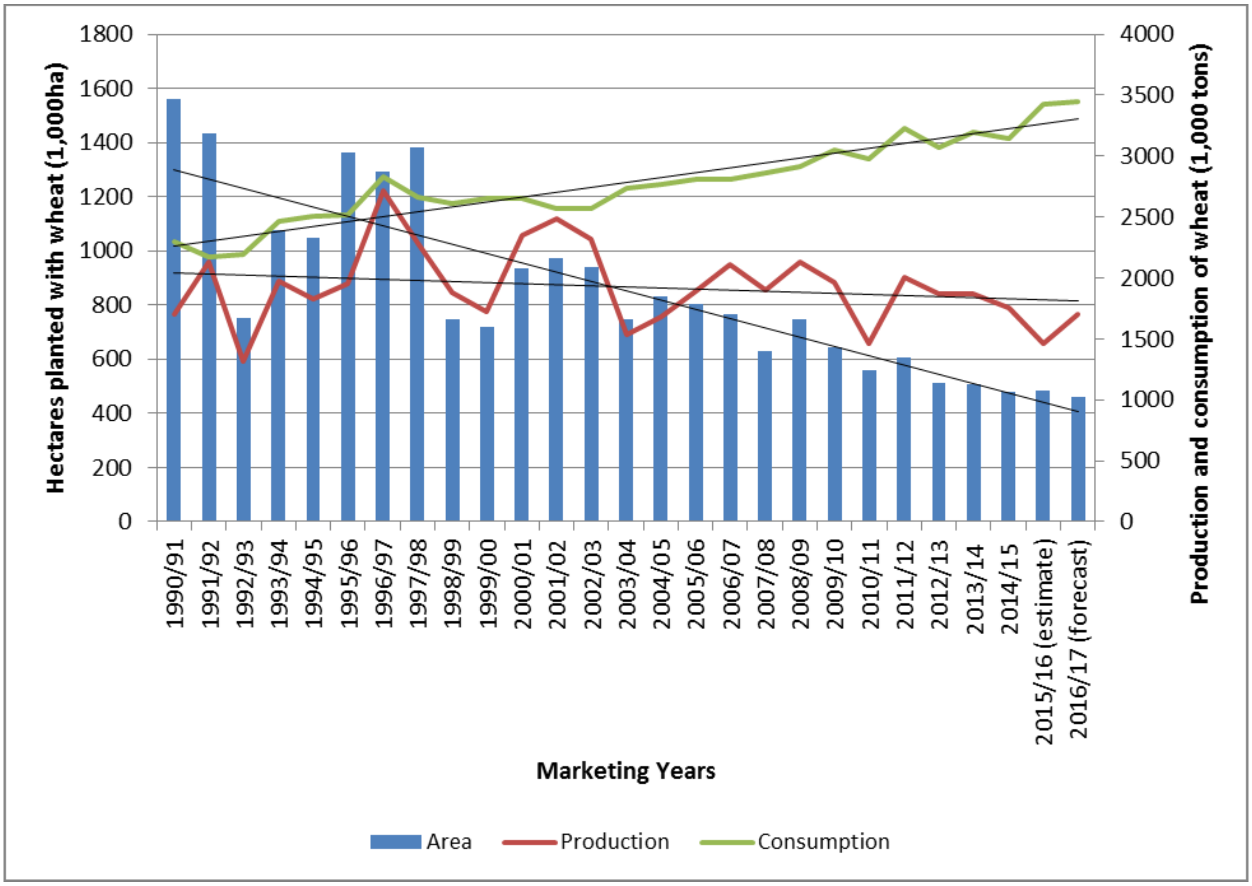


Figure 2.3 The trends in wheat production, consumption and areas planted in South Africa (1990/91 – 2016/17) Source: USDA, 2017

The price of bread is increasing. This is shown in Table 2.3. The Brown bread price has increased by 20% and 13% from 2015 to 2017 and 2016 to 2017 respectively. The price of white bread increased by 17% and 11% during the same period respectively (USDA, 2017). Though the increase in price could not be said to be related to the declining wheat production, such a relationship cannot be disputed. The South African drought conditions of the year 2015/16 forced farmers to increase winter wheat production as an alternative crop in the summer grain producing areas. As a result the wheat areas increased by 38%, especially in the Free State province (USDA, 2016; USDA, 2017).

Table 2.3 The retail prices of selected food items

Item	Jan 2015	Jan 2016	Jan 2017	% change 2015-2017	% change 2016-2017
Brown bread (700g) loaf	R10.29	R10.88	R12.31	20	13
White bread (700g) loaf	R11.42	R12.03	R13.41	17	11

Source: NAMC in (USDA, 2017).

2.5 South African food security perspective

Disasters can be triggers for food insecurity. According to the Department of Agriculture in South Africa (2002), at national level, food is secure. South Africa produces its main staple food, it exports its surplus food, and imports what it needs to meet its food requirements. The country has no domestic resource base for producing rice, rice is imported. The country has met the needs of its main staple food, such as maize, by over 100% from domestic resources. The country also met its requirements for wheat, the second most important food product, by up to 95%, livestock needs by 96% and its dairy products (excluding cheese) by 100%. Food security indicators for horticultural products and sugar are over 160% and underscore the strong position of South Africa as an exporting country of fruit and wine products to the European Union (EU). Within the SADC region, South Africa is the leading food exporter (Department of Agriculture, 2002).

The Department of Agriculture (2002) gave further projections of National food security as follows: Should current production trends hold, domestic wheat production would be outstripped by domestic consumption by nearly 60% in 2010, and by over 100% in 2020. Maize consumption is expected to exceed production by 2010, again assuming that current trends continue. This statistic continues about other commodities in the Department of Agriculture (2002), which concludes that the national food security status of South Africa will remain, consumption exceeding production, if those production trends continue.

A Decade and a half later, a 2016 BFAP baseline report indicates that the South African agricultural sector has been swinging up and down, as it depends on climate, the agricultural sector is volatile. It has been resilient, though, and able to recover on a long term view through the past decade 2005 - 2016 (BFAP, 2016). South Africa experienced the worst drought in 2015/16 since 1904. It is reported that more than 1.2 million people will be affected by this drought as the food security of South Africa can be jeopardized (BFAP, 2016). The next section reviews the vulnerability of agriculture to drought risk.

2.6 Vulnerability to drought risk

Below is a general description of the types of drought, and it takes us close to the objective of this study. It should be noted that a drought disaster emanating from an 'agricultural drought' is the one that will result in poor crop growth and ultimately lower crop yield and poor quality crop products. It should be noted that a meteorological drought may be an agricultural drought and not vice versa. Therefore, by studying the farmers' adaptation measures to climate change, we refer in this study to adaptation to drought. Furthermore, drought in this study is limited to a lack of rainfall at a particular time in the crop season, namely *agricultural drought*. This drought condition poses a risk to dryland wheat farmers in summer rainfall areas of South Africa. In certain areas and in certain years drought can result in a total yield loss and render households vulnerable to food insecurity.

Compared to all other natural disasters, drought has the biggest potential economic impact and can affect the biggest number of people. Although the death toll from other natural disasters can be high and severe, if over populated areas are affected, drought affects bigger areas. It often covers countries or parts of continents (Reed, 1992). Drought may last for months and sometimes for years. The on-set time (warning time) of drought varies between different locations, spatially and temporally. With modern rainfall and meteorological monitoring it is possible to predict food shortages that may be caused by drought. Governments should be able to mitigate the impact of drought before they become significant (Reed, 1992). There is a direct impact of drought on food production, food security and the overall economy.

There are three types of droughts: meteorological drought, hydrological drought and agricultural drought. In literature (Reed, 1992; Van Zyl, 2006; Wilhite & Glantz, 1985) the droughts are described as follows:

> *Meteorological drought* involves a reduction in rainfall for a specified period (day, month, season, and year) it is below a specified amount, usually defined as some proportion of the long term average for the specified time period. Meteorological drought is linked to the average rainfall in certain areas.
>
> *Hydrological drought* is a reduction in water resources (surface and sub-surface) below a specified level for a given period of time. It involves the water supply and demand in relation to the normal operations of systems being supplied (domestic, industrial, irrigation).
>
> *Agricultural drought* is when there is not enough soil moisture to meet the needs of a particular crop at a particular time of its growing cycle for optimum growth.

Drought has been studied widely. Wilhite & Glantz (1985) mentioned that in a review of drought studies the difination of drought was a major disagreement among those studies, more that 150 definations were found according to Wilhite. It is evident that studies on drought computations (Lourens & De Jager, 1997; Du Pisani, et al., 1998; De Jager, et al., 1998), studies on drought impact (Thompson & Powell, 1998) and studies on drought policy framework continually added to the toll (Meagher, et al., 1998). One perseption of drought (Wilhite & Glantz, 1985) stated that how societies perceive drought determines the likely response to drought by those societies. This statement is supported by other authors as well.

In South Africa three main rainfall regions have been identified (Benhin, 2006). They are:

- The winter rainfall region in the South-Western Cape with less than 500 mm per year;
- The area with rainfall throughout the year along the southern coastal region, with more than 700 mm per year; and

- The summer rainfall area in the rest of the country (approximately 86%) with rainfall between 500 mm and 700 mm per year.

The driest province is the Northern Cape and the wettest is KwaZulu-Natal. The Western Cape, the second driest province, receives mainly winter rainfall. The rest of the country receives summer rains in the form of thunderstorms. Only 10% of the country receives an annual precipitation of more than 750 mm. This includes the northern parts of the Eastern Cape Province, the coastal belt and midlands of KwaZulu-Natal and the Mpumalanga low veld. Only about one-third of the summer rainfall areas receive an annual precipitation of 600 mm or more. This is close to the lowest limit for successful dryland crop production (NDA, 2001b) cited in Benhin (2006). The following section reviewed studies on farmers' perception of climate change.

2.7 Perception of farmers to climate change and adaptations for mitigation

Perception is a prerequisite for adaptation. A greater influence of perception is the indigenous knowledge of the people. Perception is also determined by factors like age, experience, education, environment, access to irrigation and access to information on weather and climate. This is according to Amadou et al. (2015) and Gadédjisso-Tossou (2015). These determining factors are not in the scope of this study. Cooper et al. (2015) advises that the perception of farmers on climate change must be properly analyzed by proper statistical methods with trends of other drivers to ascertain perceptions such perception.

The reviewed literature indicate that the farmers' perception of climate change is that there is a change in temperature, there is a change in rainfall, there is a change in season (rain on-set and end), and there is a change in the frequency of dry spells within the seasons in the past 20 years (Amadou, et al., 2015; Cooper, et al., 2015; Gadédjisso-Tossou, 2015; Apata, 2011; Abid, et al., 2015).

Wilhite & Glantz (1985) mentioned that the way societies perceived drought determines the likely response to drought by those societies. Adaptation strategies by farmers to climate change is a subject that many institutions want to address, investigate and promote. Climate change adaptation strategies for the diverse farming system in Sub – Saharan Africa must be promoted (Cooper, et al., 2015). This piece of literature supports a piece by Gadédjisso-Tossou (2015) were it was found that 42% of the farmers who indicated that they perceived a change in the climate did not adapt to it. Abid et al. (2015) further found a lack of money was among the reasons for the non adaptation.

Adaptation is widely recognized as a vital component of any policy response to climate change. It is a way of reducing vulnerability, increasing resilience, moderating the risk of climate impacts on lives and livelihoods, and taking advantage of opportunities posed by the actual or expected climate change, Acquah-de Graft & Onumah (2011) cited in (Gadédjisso-Tossou, 2015). Commercial farmers produce food to feed the country. Therefore adaptation in commercial farming is a means towards attaining national food security. The adaptation strategies will play an important part in limiting the nation's vulnerability to climate disruptions on food supplies. Adaptation strategies will only be successfully adopted if there is an enabling policy and institutional environment that will assist in dealing with barriers to adaption. Such guarantees are necessary to guarantee food security to more vulnerable people, as well as guarantee that income losses will be limited for farmers that are more vulnerable (Cattaneo, et al., 2012).

2.8 Adaptation measures to mitigate the impact of climate change on agriculture

This study is not about the determining factors that influence the farmer's choice of adaptation measures to climate change. This study is under the assumption that the commercial wheat farmers in the study area perceive climate change and the variability in one way or another. Therefore the survey has determined which adaptation measures are used or are considered for use by most farmers, as presented in Chapter 4. Once determined, those adaptation measures are used as factor inputs to the crop model. Adaptation measures used by farmers who perceive climate change are: mixed planting, planting date, different crop cultivars, planting of short season varieties, planting shade trees and changing fertilizers, among others. Studies of these adaptation measures are reviewed in the paragraphs below.

In Gadédjisso-Tossou (2015) seven adaptation measures were identified in the Togo study area, to counteract the effect of the increased temperature, reduced rainfall and changing rainfall patterns. The major adaptation measure to climate change appears to be planting a short season variety (20.38%) changing crop planting dates (17.87%), while crop changing was identified by only a few (0.94%). Planting a short season variety is the most commonly used method, whereas crop changing is the least practiced method among the major adaptation methods identified in that study area. This can be seen in Table 2.4.

Table 2.4 Adaptation strategies in response to the change in temperature and precipitation % respondents (Gadédjisso-Tossou, 2015)

Adaptation strategies	Respondents (%)
Crop diversification	9.72
Change in crops	0.94
Find off-farm jobs	3.76
Change the amount of land	1.88
Change planting dates	17.87
Plant short season variety	20.38
Other	3.76
No adaptation	41.69

A study in Pakistan showed that the most common adaptation measures were changing crop varieties (32.20 %), changing planting dates (28.40 %), planting shade trees (25.30%) and changing fertilizers (18.70 %). These were followed by changing cultivars (10.20 %), increasing irrigation (9.80 %), soil conservation (9 %), crop diversification (7.56 %), migration to urban areas (3 %) and renting out land (2.20 %). This is shown in Figure. 2.4 (Abid, et al., 2015).

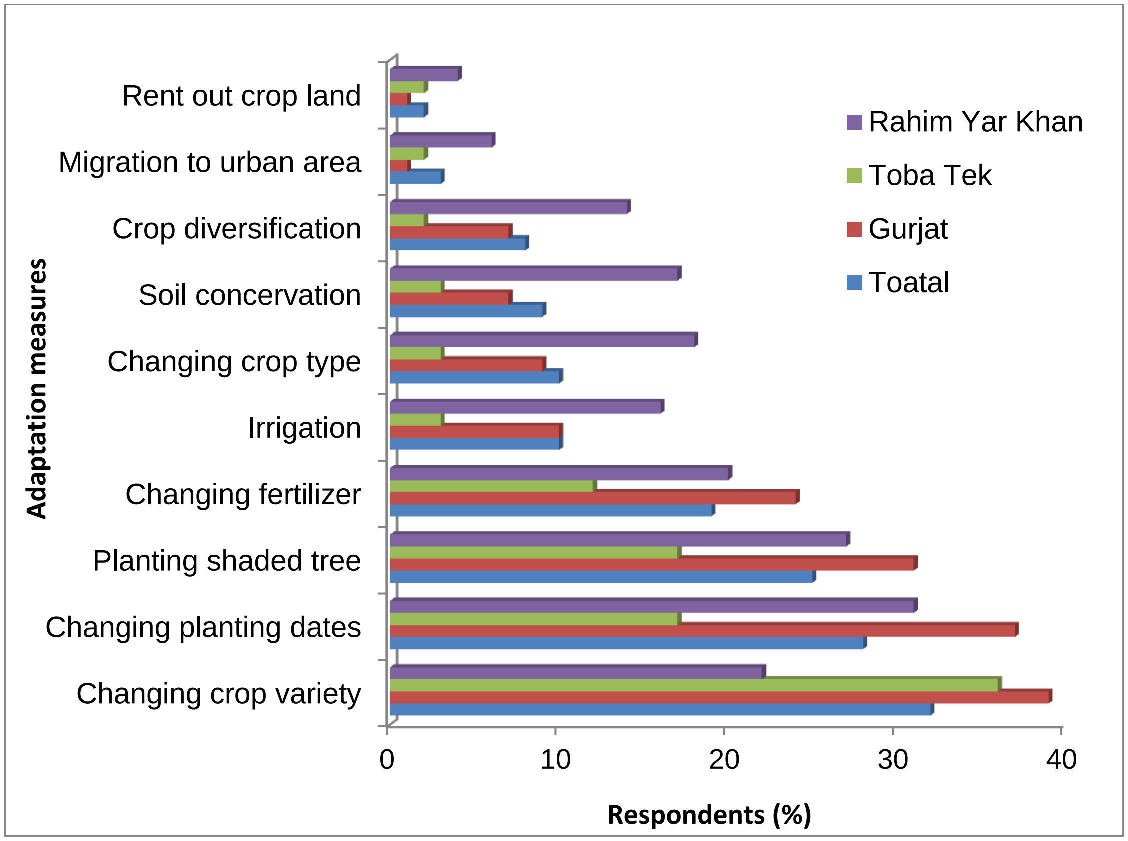


Figure 2.4 Adaptation measures adopted by farmers across three study areas in Punjab, Pakistan (Abid, et al., 2015)

In a study by Apata (2011) in Nigeria, the analysis showed that mixed crops (57.4%) are the most common adaptation method used, followed by planting date (44.6%) to variability in climate (Table 2.5).

Table 2.5 Adaptation options adopted by respondents from the study area in Nigeria (Apata, 2011).

Adaptation measure	Respondents (%)
Planting of trees	13.7
Mixed farming	29.7
Mixed cropping	57.4
Soil conservation	20.9
Intercropping	12.9
Mulching	22.9
Zero tillage	29.4
Making ridges	38.6
Irrigation	04.3
Planting date	44.6

It has emerged that a cultivar change and planting date are seen as low cost adaptation measures by farmers (Gadédjisso-Tossou, 2015; Abid, et al., 2015; Apata, 2011; Amadou, et al., 2015). Reed (1992) mention that farmers plant the same variety again, following a delayed monsoon, while others replant different cultivars, possibly with different maturing periods. This statistical version of adaptation studies is not well documented in South Africa. The optimum panting time for dryland wheat in the South Western Free State (Bloemfontein included) ranges from the 2nd week of April to the last week of June. In the Eastern Free State (Bethlehem included) it ranges from the 2nd week of May to the 2nd week of August. This is according to the planting ranges of the different cultivars (ARC-SGI, 2013). The following section reviewed the crop simulation models that simulate plant growth.

2.9 Crop simulation models and climate change scenarios

2.9.1 Crop simulation models

Models are important tools for researchers to use if they are interested in assessing the integrated impacts of different components of climate variability and climate change on rain fed agricultural production (Cooper, et al., 2015). Developments around crop modeling date far back and it is well documented (Singels, et al., 2008). For this study a DSSAT crop simulation model was used, however evaluation by other crop models is also considered in this literature review. The DSSAT model requires, as a minimum, climate data; soil environment data; gene/cultivar coefficient data; and management data (Basso, et al., 2013; Jones, et al., 2003).There is ample literature available on the nature and operation of the DSSAT. The literature proves that the DSSAT and other models have evolved with research and scientific needs, to remain useful tools to use for today's challenges of climate change in agriculture (Jones, et al., 2003; Nkulumo, et al., 2013; Ewert, et al., 2014).

For modelling planting dates and cultivars Saseendran, et al. (2005) simulated planting date by using the RZWQM and CERES-MAIZE models. Mohammed, et al. (2010) found that yield improvement can be achieved by adopting early crop sowing in the first 10 days of July in the rain fed areas in Sudan. For fertilizers Saseendran, et al. (2004) modeled crop Nitrogen requirements under varied soil and climatic conditions. Crop models use General Circulation Models (GCM) as an output in the creation of climate change scenarios for impact analysis (Robock, et al., 1993). Basso, et al. (2013) elaborated on the use of crop modeling as a tool for an Early Warning System. The Early Warning System is a desired management tool in disaster risk reduction.

2.9.2 Climate scenarios by GCM models

Long-term emissions scenarios were developed by the IPCC in 1990 and 1992. These scenarios (Figure 2.5) have been widely used in the analysis of possible climate change, its impacts, and options to mitigate climate change. The scenarios are alternative images of how the future might look like and are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties. Scenarios assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation (IPPC, 2000).

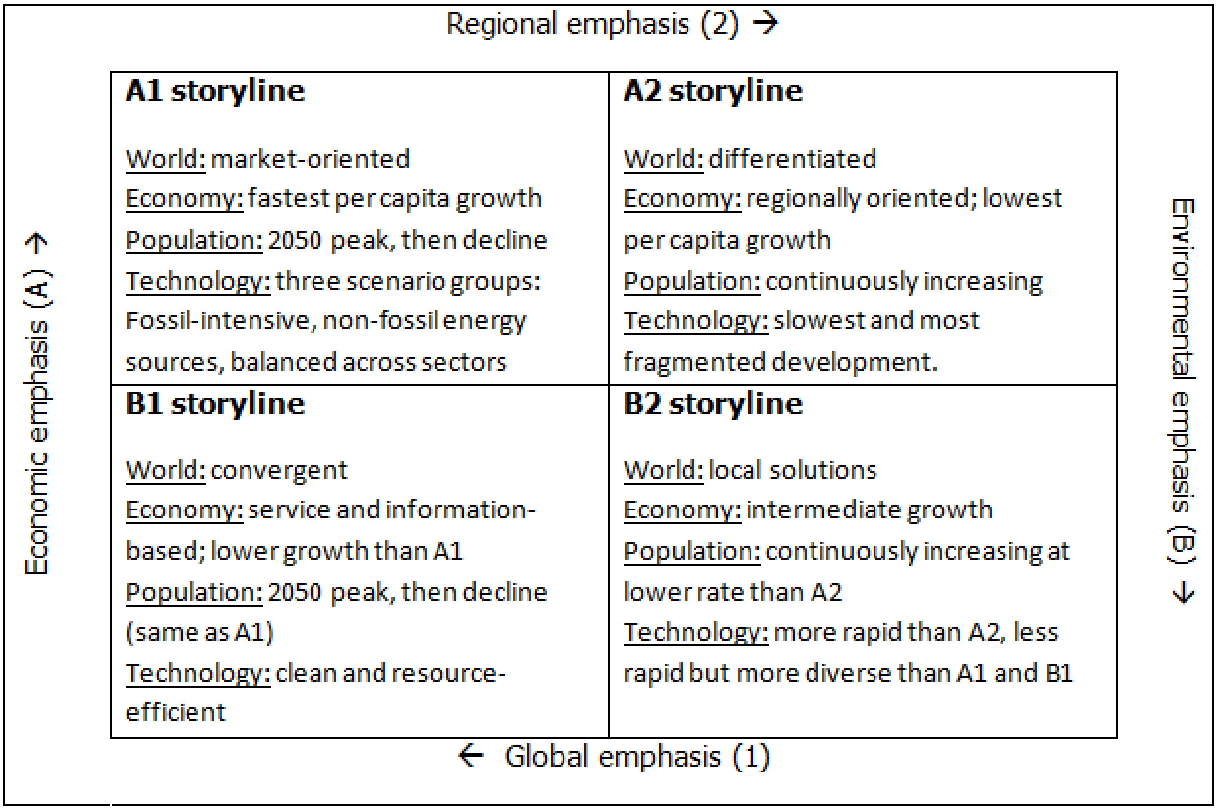


Figure 2.5 Summary characteristics of the four SRES (Special Report on Emissions Scenarios) (Source: http://www.toolkit.balticclimate.org)

In climate impact studies the impact of climate change is predicted by introducing varying climatic scenarios to the baseline weather to derive a future climate with reference to the Global Circulation Models (GCMs) as described by (Abraha & Savage, 2006; Walker & Schulze, 2008; Paolo, et al., 2015). Many climate change studies has emphasized the findings that atmospheric carbon dioxide (CO_2) concentration will rise from the current concentrations due to the industrial pollution that the earth is experiencing. Sub-Saharan Africa and South Africa in particular is not spared from such a global trend. Global warming also impacts on daily temperatures and the subsequent precipitation in different regions. Erratic rainfall patterns are among the results of global warming. The next section reviewed how farming practices were simulated to test viable adaptation measures to climate change conditions.

2.10 Simulations of crop adaptation measures

Crop adaptation strategies to mitigate the impact of climate change are introduced into the model to determine the viable management options. Those models that tested planting date, cultivars/variety and crop rotation are considered helpful to this study. In Kenya and South Africa models found that yield decrease was less when farmers adopted planting date as a management option to mitigate the impact of climate change (Waha, et al., 2012).The variables of interest from the simulation output are mostly growth and development, biomass accumulation, and grain yield.

2.10.1 Changing planting date to mitigate impact of raising temperature

Crop production is naturally sensitive to climate variability. The rate of plant development is mainly determined by temperature. Warmer temperatures that shorten the development stages of a determinate crop, will most probably reduce the yield of certain cultivars (Attri & Rathore, 2003).

Modeling wheat phenology under IPPC scenarios (Figure 2.5), Attri & Rathore (2003) results indicate that the duration of anthesis decreased by 0.9–3.6% under an A1 scenario, whereas there was an increase in duration of the order of 0.9–1.8% under an A2 scenario, compared with normal sowing under the projected climate in normally sown cultivars, *viz.* WH542 and HD2329. However, the reverse was observed in late-sown cultivars, *viz.* an increase under an A1 scenario (1.0–1.1%) and a decrease under an A2 scenario (1.1–2.0%). Simulated maturity was similar to that of anthesis in all the cultivars in the study (Attri & Rathore, 2003). In an experiment by Ouabbou & Paulsen (2000) it was shown that altering the planting dates in 1994 successfully changed the temperature regime during maturation of the wheat cultivars. Cultivars planted on the first date reached anthesis on a mean date of 3 March and physiological maturity on 4 April. Those planted on the second date flowered on 28 March and matured on 18 April. Planting on the third date delayed mean dates of anthesis to 18 April and physiological maturity to 5 May. The mean daily high temperature from anthesis to physiological maturity was 25, 28, and 31ºC for the first, second, and third plantings, respectively.

2.10.2 Changing planting date to mitigate impact of rainfall pattern

The planting date, as a crop management practice, was included in a seasonal DSSAT study set up in Ethiopia. Planting date has proven to be among the best practices of all the treatments in that study. The results indicated that durum wheat production might have been affected by a decrease in the seasonal rainfall amount, a high variability in the rainfall amount and the intensity of the rainfall throughout the wheat growing period. This might have happened despite, the onset, duration and end date of the main rainy season (Abayisenga, 2015).

Terminal drought occurrence has a high probability. Focusing on agronomic practices, such as using early maturing cultivars, in situ moisture conservation practices, etc. might help to offset the impact due to terminal drought and prolong the growing period during the main season. In that study Abayisenga (2015) predicted an increased grain yield by 2050 and 2080 under the GCM model scenario and stated that this means that crop management options may have a positive impact on increased yield under future climate change (Figure 2.6). An in situ moisture conservation practice is a pre-requisite for rain fed wheat production in the Bethlehem area. Unlike Ethiopia and other places, wheat in Bethlehem is planted during the dry season when there is no rainfall expected. The said moisture conservation practices are supposed to ensure enough moisture in the soil to sustain the crop until it is closer to the flowering stage when the first rain of the wet season is expected.

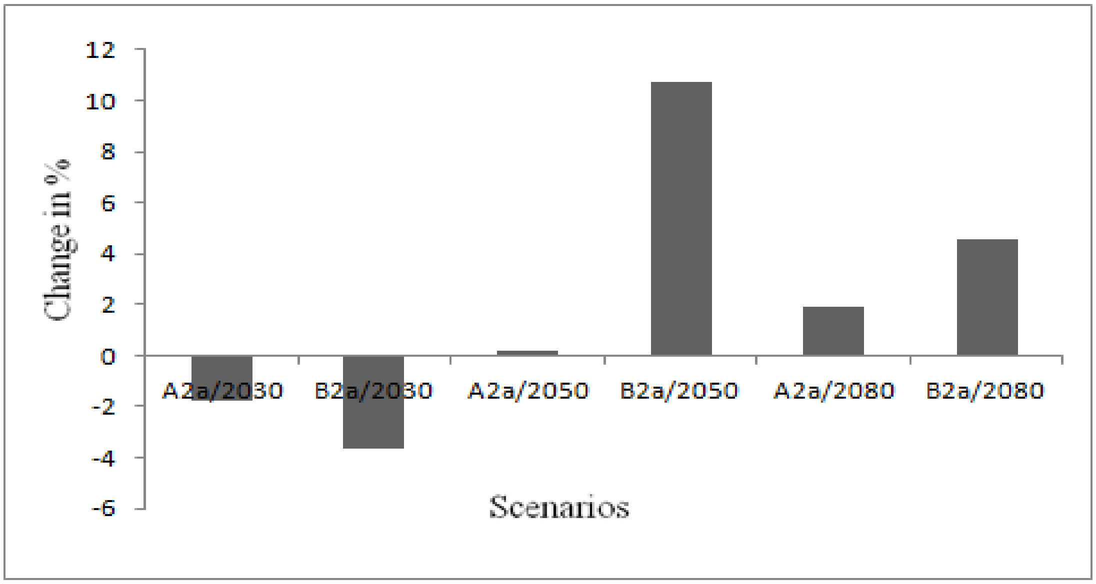


Figure 2.6 Change in percentage of yield for variety Yerer (Abayisenga, 2015)

According to Abayisenga (2015) there are benefits that could be derived from the dry month during the harvesting period. This is the case with the Bethlehem wheat production, where rainfall during the harvest may result in delayed harvesting. Some cultivars tend to sprout quickly prior to harvesting when the moisture allows it. All this can possibly be mitigated by the optimum planting time and the choice of a suitable wheat variety.

2.10.3 Changing cultivar to mitigate impact of temperature

Abayisenga (2015) found that the relationship between grain yield and increasing atmospheric CO_2 concentrations was positive non-linear under 710 ppm for cultivar Yerer. The underlying reason may be due to the fact that Yerer is a cultivar that performs well in waterlogged conditions that prevailed in that area (Abayisenga, 2015).

Focusing on two different cultivars that were well-irrigated and fertilized, the number of days to anthesis and to maturity and the accompanying yield declined with the increasing temperatures in the cultivar experiment grown at the International Maize and Wheat Improvement Center (CIMMYT). The same temperature responses were shown by using model simulations. The cultivars Bacanora and Nesser used in the CIMMYT experiments in various locations might be more heat tolerant as it is known that cultivars have different mechanisms of tolerating heat (Asseng, et al., 2015).

2.10.4 Changing cultivar to mitigate the impact of rainfall pattern

The CERES-Wheat model was calibrated to evaluate the impact of climate change. Wheat cultivars that are popular in India were tested. The results indicated that the model has the ability to simulate the yields of different cultivars in diverse environments (Attri & Rathore, 2003). Such diverse environments are usually characterized by inter season variations. Evaluating the performance of different cultivars in Algeria Rezzoug, et al. (2008) also found significant variations across cultivars for a given year, with grain yields differing by a factor of 1.5 to 2 between the lowest and highest yielding cultivars.

2.10.5 Changing crop to mitigate the impact of temperature and rainfall

According to Tubiello, et al. (2000) when investigating adaptation strategies, it was found that a combination of early planting for spring–summer crops and the use of slower-maturing winter cereal cultivars has kept the crop yields unchanged. Haverkort, et al. (2013) tested the model in three regions which indicated that potatoes are not negatively affected by expected increases in the average temperatures for Southern Africa. These findings suggest that potatoes are an alternative crop in mitigation of crop yield losses because of increases in temperature.

2.11 Conclusion

Following the literature reviewed it is clear that South Africa has a national legislative framework and strategies for disaster risk reduction. Those strategies appear to be in cohesion with the regional strategies. South African crop production is properly addressed in those policy frameworks. The review also shows how scientific and technological information can play a major role in monitoring hazards as well as developing tools and methodologies for Disaster Risk Management. Climate information, drought in particular, crop management information and crop farming practices can all benefit from this. The reviewed literature shows how food security is impacted by agricultural drought, and the economic importance of such a condition. The perception of farmers to drought is believed to influence the way they adapt to it. Computations and the modeling of drought has proven useful in finding possible solutions (Table 2.6). It is therefore left to this study to assess and give preliminary recommendations on farming practices that can be used as adaptation measures to climate change in the study area.

By bringing into action those strategies and integrating all the information into building a sound warning system, we can help to encourage appropriate farmer adaptation measures to mitigate the impact of climate change in our crop production systems in South Africa. The next chapter discusses the methods and materials employed in this study.

Table 2.6 Evaluation of climate change adaptation measures in wheat production by crop simulations

Adaptation measure studied						**Research Description**			
Temperature (T)			**Rainfall (RF)**						
A-T	**B-T**	**C-T**	**A-RF**	**B-RF**	**C-RF**	**Resulting impact**	**Model**	**Study area**	**Source**
X		X			X	- Duration to anthesis, - Grain yield	CERES-Wheat scenarios	India	Attri & Rathore, (2003)
X		X				- Duration to anthesis - Photosynth-etic rate	Field trials	Morocco	Ouabbou & Paulsen, (2000)
		X	X		X	- Grain yield	DSSAT IPPC scenarios	Ethiopia	Abasiyenga, (2015)
		X				- Duration to anthesis, to maturity - Grain yield	Multi-model crop Sim.	CIMMYT Sites	Asseng et al., (2015)
	X					- Crop yield	LINTUL1	South Africa	Haverkort et al., (2013)
	X					- Crop yields - Dry matter accum.	CropSyt. GCM	Italy	Tubiello et al, (2000)
					X	- Duration to anthesis - Grain yield	DSSAT	Algeria	Rezzoug et al., (2008)

***NB: A = Changing planting date, B = Changing crop and C = Changing variety*.**

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methods followed in this study. The chapter includes the description of the study area, Bethlehem. A description given includes: population and demography, climate, soils as well as agriculture and economic activities. It describes methods and tools used to gather primary and secondary data, which include, archive data base, farmer survey, interviews with senior government officials, consultants and agricultural extension officers and other stakeholders, organizations and the historical weather database. The crop simulation model of choice and model calibration and evaluation is also described in this chapter. Finally the chapter indicates the statistical analyses that was followed to analyze data and to evaluate the crop simulation results.

3.2 Description of study area

3.2.1 Location

The Bethlehem area (Thabo Mofutsanyana District) is located in the north-eastern part of the Free State Province, Republic of South Africa (28˚ 57' S, 25˚ 53' E, 1200 to 1640 m a.s.l. [above sea level]). The Bethlehem area was selected for a case study because it represents one of the large-scale commercial wheat farming systems (Figure 3.1). The Bethlehem area is surrounded by farming locations such as Slabberts, Kraansfontein, Clarens, Twishoek, Paul Roux, Sharedan, Afrikaskop, Kestell, Fouriesburg, and Reitz (Free State Provincial Government, 2010). As illustrated in Figure 3.1 in the Bethlehem area wheat is sown under dryland conditions by using the stored soil moisture that was obtained during the preceding summer / autumn season.

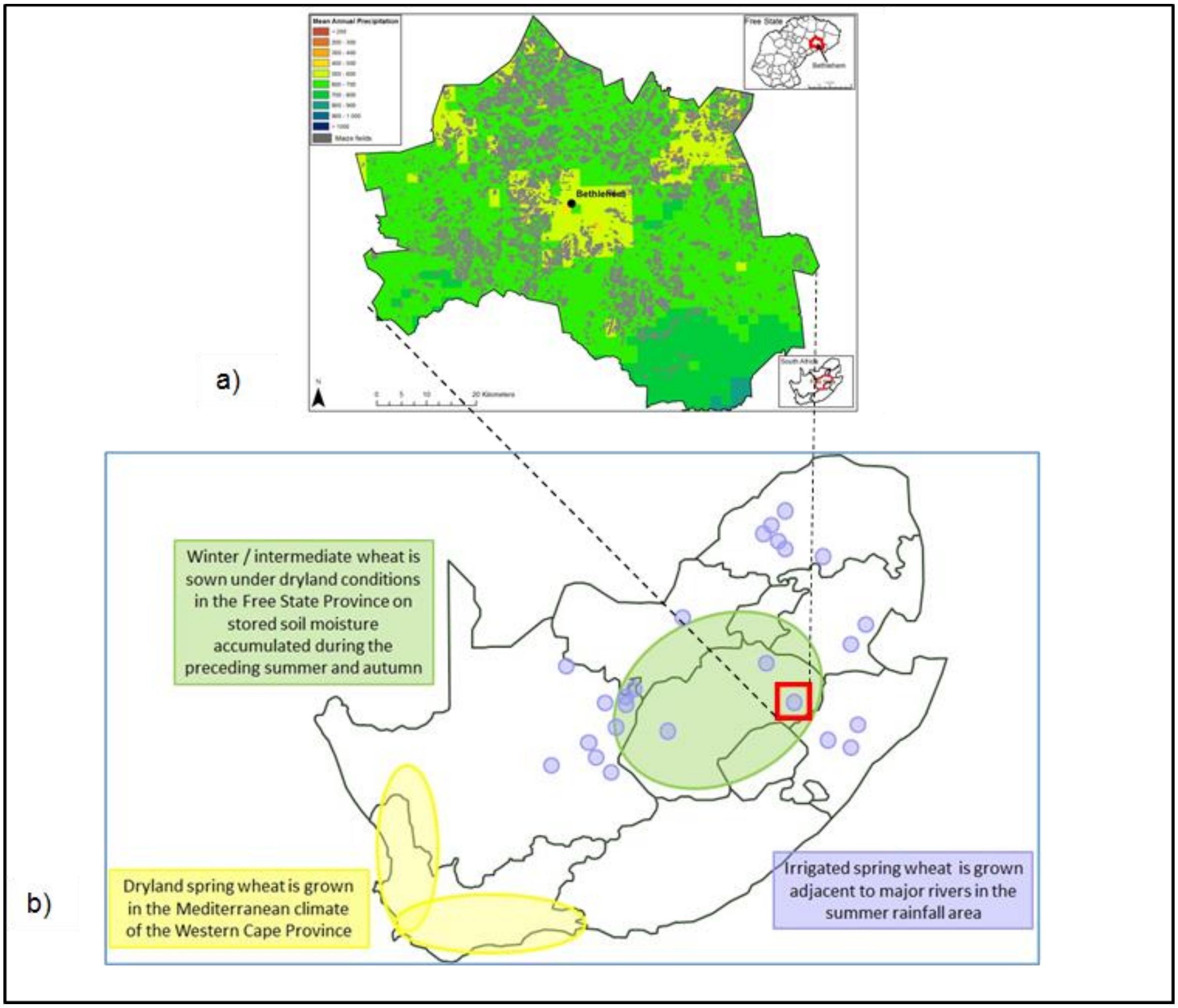


Figure 3.1 Location of case study: **a)** Bethlehem area, in the Free State, Republic of South Africa. Colors on the map represent amounts of rainfall and the grey color represents cultivated wheat/maize fields (Beletse et al., 2014). **b)** Wheat growing area in South Africa (ARC-SGI, 2013)

3.2.2 Population and demography

The population of Bethlehem is 76 020, composed of: 85% black African, 11% white, 2% colored and 2% other groups (City Population, 2017). 66% of the Free State population is classified as poor, with the majority living in rural areas. With a contribution of 9% to the GDP of the province, agriculture is considered the third biggest contributor after, mining and tourism (Free State Provincial Government, 2010). There is a high proportion of the informal labor force in the area which, according to the Free State

Provincial Government (2010), is an indication that mico-eterprises are a way of survival and that there is a large propotion of empoverished people.

3.2.3 Climate

The climate of the region is characterized by summer rainfall (October–March), with an average rainfall of about 650 mm per year. The highest average maximum temperature is in January (30^{o}C). The lowest average minimum temperature is in July (1.5^{o}C). There are frequent occurrences of frost during the winter months due to the high altitude and proximity to the Drakensberg Mountains (Beletse, et al., 2014).

3.2.4 Soils

The Bethlehem soils are dominated by well-drained loamy to sandy loamy textured soils with a pH of about 6.0 to 7.5. Wheat requires a large soil water holding capacity to ensure sufficient soil water storage during the development stage. Soil types commonly found in the Bethlehem area are Avalon, Westleigh, Clovelly, Longlands and Pinedine. These soils have a heavy clay layer, or barrier layer, that prevents stored water from draining and are therefore suitable for soil water storage (ARC-SGI, 2009). Most Bethlehem soils are able to store enough moisture to help with the germination of the wheat seeds after planting in the winter season. To ensure sufficient soil water storage for dryland wheat production in the summer rainfall region, soils with large water holding capacities are therefore needed to vigorously grow the wheat seedlings. In general, Bethlehem soils are high water table soils that store moisture during the summer rainfall season for the winter crops.

3.2.5 Agriculture and Economic activities

The economy of the area is largely dependent on agriculture and agri-business, tourism, and retail businesses. Commercial farming is the main supplier of employment. Crops produced are Wheat, Maize, Potatoes, and Fruits. Livestock farming is also part of the commercial farming in this area. There are pockets of communal subsistence farming in each of the locations surrounding Bethlehem. According to the Free State Provincial Government (2010) those subsistence farming activities are food security projects, supported by the Provincial Government and municipalities to alleviate unemployment and food security challenges. They mainly include poultry, vegetables, dairy, and piggery projects, with other non-agricultural projects such as sewing, and sand stone mining (Free State Provincial Government, 2010). Bethlehem is the hub of the country's wheat production under summer rainfall conditions. Wheat production in Bethlehem and the surrounding areas is produced mainly under rainfed conditions. Bethlehem produces 47% of the country's wheat crops (ARC-SGI, 2009).

3.3 Research methodology

3.3.1 Review of the Disaster Risk Management framework in South African agriculture

To address the first objective of the study, two approaches were used. Firstly, a secondary source of information was collected, to review the Disaster Risk Management in South Africa in relation to agriculture and the vulnerability of food security. The Disaster Management legislative framework was used as the basis of such a review (National Disaster Management Framework, 2007; Disaster Managment Act, 2008). Secondly, following the review of the legislative framework, a consulted interview with other stakeholders was conducted. A senior Manager of Disaster Management of the Department of Agriculture Forestry and Fisheries (DAFF) in the Free State province and an Area Manager of the Crop Insurance Company in Bethlehem were interviewed as sources of primary information. Non-structured interviews were conducted through using a key informant questionnaire (appendix II). The interviews served to partially clarify and ascertain some aspects of the Disaster Management legislative framework in relation to wheat production in the Eastern part of the Free State. The interviews also clarified certain aspects that emanated from the wheat farmers' responses to the questionnaire about crop insurance and state relief programs.

3.3.2 Farmer survey

To address the second objective of the study a survey method was used in order to obtain the perspective of wheat farmers on climate change and their adaptation measures. This study is not about factors that influence or determine the farmer's choice of adaptation measures. The study is under the assumption that the commercial wheat farmers in the study area perceive climate change in one way or another. Therefore the survey proceeded to determine which adaptation measures are used or are considered for use by most farmers. The most common adaptation measures that were used as factor inputs to the crop simulation model that was sourced in this study. A farmer survey by means of a structured questionnaire (appendix I) was conducted to establish the perspective of wheat farmers on climate change and the adaptation measures. A nonprobability sampling approach was followed where 30 commercial wheat farmers in the Bethlehem area were interviewed. Thirty was the number we were able to find given the time constrains under which farmers operate, although we aimed to get more. Unlike a probability sampling, a nonprobability sampling is a sampling that does not guarantee representation of each segment of the population by a sample. The selection of farmers was based on their high management level, and availability of reliable farm records (Leedy & Ormrod, 2005). A descriptive analysis was done of the questionnaire to obtain the perspective of farmers on climate change and variability, the adaptation options adopted by famers as mitigation. Inputs from the senior disaster management practitioners backed up the analysis.

3.3.3 Crop simulation model (DSSAT)

To address the third objective of the study, the adaptation measures were evaluated using a DSSAT crop simulation model. The survey has served to determine which adaptation measures are used or are considered for use by most farmers. Once determined, those adaptation measures were commonly used as factor inputs in the crop model. Since this study attempted to investigate climate change and its impact on wheat farmers' production as well as assessing the potential of three adaptation strategies to adapt to climate change, a combination of quasi (semi) experimental data and survey information was used for the model simulation. The adaptation measures are planting date, change of cultivar and the rate of nitrogen fertilization. It is evident from the survey that fertilizer was not indicated as the preferred adaptation measure by many farmers. This practice is included in the model because of the high cost of fertilizers in crop production, which makes fertilizer an important crop production input, but farmer’s still practice application of fertilization to boost the production.

A crop simulation model CROPSIM - CERES embedded in the DSSAT-Version 4.6 (Jones, et al., 2003) was used to simulate wheat under rainfed conditions. The DSSAT model requires, at minimum, climate data; soil environment data; gene/cultivar coefficient data; and management data (Basso, et al., 2013; Jones, et al., 2003). For a simplistic biophysical crop modeling protocol, such data requirements were provided from the University of the Free State, Department of Soil, Crop and Climate Sciences (Agrometeorology section). Wheat crop management practices were obtained from literature (White & Edwards, 2008; ARC-SGI, 2013).

3.3.3.1 Model calibration

Weather and soil dataset, agronomic practices and a cultivar genetic coefficient are the main inputs to run the model. The DSSAT model was calibrated according to location, three cultivars and common practices of commercial farmers as documented from various literatures (Jones, et al., 2003).

Climate data: climate data for the Bethlehem location was used as a long series weather data base. The historical long-term weather data was used as a baseline for the reference period of 30 years, from 1980 to 2010. The data used is daily temperature, rainfall and solar radiation together with longitude, altitude and the elevation of the Bethlehem location. The weather data file was formatted onto the DSSAT model format and loaded as met. File.

Soil data: Soil data includes physical and hydrological properties of the local soil also provided from the University of the Free State, Department of Soil, Crop and Climate Sciences (Agrometeorology section). The chemical properties of the soil were lacking from the soil data. However, the model was able to calculate the soil Nitrogen content with the available data input. Soil parameters used as inputs to the model are shown in appendix III.

Cultivar parameters (coefficients): The model was calibrated with three wheat cultivars whose coefficients were obtained from the cultivar adaptation experiment of the Agricultural Research Council - Small Grains Institute (ARC-SGI, 2013). The crop parameter requirement for wheat crop simulations is, optimum vernalizing temperature, required for vernalization (days), photoperiod response (% reduction in rate/10 h drop in pp), grain filling (excluding lag) phase duration (^{o}C.d), kernel number per unit canopy weight at anthesis (#/g), standard kernel size under optimum conditions (mg), standard - non-stressed mature tiller wt (incl grain) (g dwt), and interval between successive leaf tip appearances (^{o}C.d) (Jones, et al., 2003). Three cultivars were used, Betta DN, SST124, and Elands. The cultivar coefficients for those three cultivars are shown in Table 4.7.

3.3.3.2 Simulation

Management: Crop adaptation strategies to mitigate the impact of climate change were introduced into the model to determine the viable management option. The model was calibrated with two planting dates, early planting set at 5 June and late planting set at 18 July. The planting dates were chosen because they are within the planting window period for Bethlehem, Eastern Free State. Seeds were planted in 45 cm inter-raw soil, 4 cm deep and 111 plants per m^2, with a 90% germination. Plot size was 5m long and 5m wide. Harvest area was 4m long row length and 9 rows. The model was calibrated with three wheat cultivars. Elands is a medium maturing cultivar, has a medium to high yield potential with excellent hectoliter mass. SST124 is a somewhat early maturing cultivar, with a low to medium yield potential. Betta-DN is a medium maturing cultivar, with a low to medium yield potential, with excellent hectoliter mass. The cultivars are well known and commonly used by the farmers of Bethlehem since the early 2000's. The model was calibrated with three levels of nitrogen management, a low level of 25 kg N, a medium level of 50 kg N and a higher level of 75 kg N per hectare. The nitorgen source was Ammonium Nitrate, applied at planting and banded beneath the surface. Phosphorus and potassium were applied as 15 and 0 kg per hactre respectively. Inspite of the lack of a detailed soil fertility analysis, fertilization was also in line with the fertilization guidelines for the Eastern Free State (ARC-SGI, 2013). Other fertility management tools (e.g organic matter) were not used. With regard to tillage, cultivated fields were selected and set 4 days prior to planting.

Simulation control: The model was run for 30 years of wheat seasons without irrigation. The model executed harvesting on the 10th December which is about 20 to 30 days after maturity, depending on the season and variety differences. Wheat harvesting in the Eastern Free State begin during this period. The variable of interest from the simulation output is the grain yield. The model output is obtained in a notepad format and transformed to an excel spread sheet to allow plotting of graphs and model evaluation.

3.4 Statistical analysis and Model evaluation

3.4.1 Statistical analysis

Survey data was subjected to a descriptive analysis by use of an excel spread sheet to gain the perspective of wheat farmers on climate change. Descriptive statistics are used to describe the basic features of the data in a study (Trochim, 2006; Leedy & Ormrod, 2005). The descriptive statistics describe data in way that is meaningful and useful. The studies related to farmer adaptation, descriptive analysis showed informative results in different places (Vedwan & Rhoades, 2001; Hageback, et al., 2005; Maddison, 2006). The data is summarized in the result chapter as a tabulated description, graphical description and discussion.

3.4.2 Model evaluation - DSSAT

The simulation model is validated by comparing the model outputs and the experimental observations. This ensures that the model simulate the outcomes that represent the natural system adequately (Pasi, 2014). For validation and evaluation of the model, yield data of the field trials published in ARC–SGI yearly production guideline was used (ARC-SGI, 2013). We ran the model for 3 years, from 2009 – 2011, and validated the model. Regression of observed versus simulated output (Stockle, et al., 2004; Jones, et al., 2003) was developed. When satisfied, we finally ran a 30 year simulation. The variable of interest was the final grain yield in both the trail and the final simulation. In addition to the derived mean yield and standard deviations, the simulation yield output was subjected to a Probability Distribution Function analysis for representation of probabilistic yield projections as probability of non-exceedance (UK, 2017). The results are presented in chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter is divided into six sections. Section 4.1 is the introductory part and Section 4.2 presents the results on the Disaster Risk Management legislative framework and its prominence to dryland wheat production in the Bethlehem area, South Africa. Section 4.3 presents the commercial farmers' perspective of climate change and variability on wheat production and the farmers' adaptation options. Section 4.4 is the section that presents the evaluation of farming management practices as adaptation options to mitigate the impact of climate change on wheat yield using the crop simulation model, DSSAT. The preliminary developed Agricultural Decision Support Tool is in Section 4.5. Section 4.6 is the last section, bearing the discussion of the results.

4.2 South African Disaster Risk Management Framework, its prominence to wheat production in Bethlehem

The first objective of this study was to review the Disaster Risk Management framework in South Africa and its prominent address to wheat production risks in the Bethlehem region, South Africa, which is vulnerable to climate change. The result from this study showed a review of the Disaster Risk Management framework in South Africa and its address to agriculture and food security vulnerability due to climate change. Further results showed that the scaled down policy framework finds its prominence in the wheat farmers in the Bethlehem area in the Free State province, South Africa. By means of a literature review, a farmer' survey and stakeholder interviews the first objective of this study was addressed as follows.

4.2.1 Legislative framework

The result was established based on the existing South African policy and legislative framework on Disaster Risk Management that is applicable for crop production and food security. The policy is well-articulated to address the vulnerability of crop production due to climate change and any form of disaster and its impact on food security. The reviewed results are presented in the series of boxes below and summarized in Table 4.1.

In South Africa, prevention and mitigation of disaster is advocated by the Disaster Management Act 57 of 2002 sections 20, 33, and 47.

Box 1

The Disaster Management Act 57 of 2002

- This act advised the formation of a policy framework for disaster management in South Africa published in 2005. This is *National Disaster Management Framework of 2005*. In order to comply with the Disaster Management Act 57 of 2002 and National Disaster Management Framework of 2005, the Department of Agriculture, Forestry and Fisheries (DAFF) has established the *Climate Change and Disaster Management Directorate.* The directorate serves to co-ordinate Disaster Risk Management functions within the sector.

The DAFF highlighted the importance of policy development and the implementation of strategies which has a bearing on this study. The link to this study in the policy framework is that the crop producers (farmers) require the intervention of research and technological advancement, and policy to mitigate the impact of climate change and the affects it has on food security. The DAFF constitutes this committee to learn lessons and share from research experts on the committee. The following information regarding the policy development and implementation document addresses the objective of the study:

Box 2

DAFF policy development and implementation strategy

- *National Agro-meteorological Committee (NAC)* – The NAC assists DAFF with the implementation of the early warning system in support of disaster risk management. This committee is chaired by DAFF and constitutes South African Weather Service, Agricultural Research Council, Provincial Departments and Universities where necessary.
- *National Drought Task Team* – a technical committee advising drought issues in the country. The committee is chaired by DAFF (secretariat) and participants include: PDA's, NDMC, Organised agriculture, Departments of Social Development, Rural Development and Land Reform, and Water Affairs.
- *National Committee on Climate Change (NCCC)* – consultation of climate change stakeholders to give an input on technical climate change issues.

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Box 3

Climate information is requisite for crop management

- Section 4 of *South African Weather Service Amendment Act No.48 of 2013* refers to South African Weather Services (SAWS) as a long-term custodian of a reliable national climatological and ambient air quality record. The long-term climate records and any other climate records are required in crop models that are used to predict crop yields and to model crop management options (South African Weather Service Amendment Act, 2013).
- *National Water Act No. 36 of 1998*, Section 137 subsection 2 sub-subsection (g) mentions the establishment of national monitoring system on water resources to assess, among other things, the atmospheric conditions which may influence water resources (National Water Act, 1998).

Section 145 subsection 2 read with subsection 1 of same Section 145 advise on establishment of a warning system in relation to events listed (drought is among them).

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It is evident that there is link between Section 4 of the South African Weather Services Amendment Act No 48 of 2013 and Section 137 and Section 145 of the National Water Act No. 36 of 1998.

South African national legislative framework and strategies for disaster risk reduction strategies appear to be in cohesion with the regional strategies.

Box 4

Regional networks

- On the regional front the African Regional Strategy for Disaster Risk Reduction was adopted by African ministers at the 10^{th} meeting of the African Ministerial Conference on the Environment in June 2004. This emerged during the development of NEPAD's operational programs with the aim to address gaps in the following areas: institutional frameworks, risk identification, knowledge management, governance and emergency response. UN/ISDR (2002) and NEPAD (2004) expanded on the regional cooperation, interactions and experience on disaster risk reduction.

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A consultant stakeholder interview with the officials from the insurance company and the Department of Agriculture Fisheries and Forestry provide highlights on how to integrate the implementation of Disaster Risk Management to reduce vulnerability. . Table 4.1 presents the summary of the views of the consulted stakeholders.

Table 4.1 Opinion of Insurance and DAFF representatives regarding disaster management

Disaster Management aspects	Insurance	DAFF*
Legislation	Financial Services Board Act (Act No 97 of 1990)	Disaster Management Act (Act No 57 of 2002)
Climate change	Presents a tougher business for the industry, considering premium levels and sensitivities to beneficiaries / clients	Proactive initiatives for adaptation & mitigation strategies, promote scenarios and awareness to climate change
Wheat insurance products	No multi-peril on winter crop There is insurance of hail and frost	No direct assistance to specific crop e.g., wheat farmer
Collaborations in disaster management	Good collaboration with agricultural financiers, and other business entities	Good collaboration with BFPA**, with other provincial administration and various stakeholders
Funds and costs	Premiums are not farmers specific, uncertainties happen in wide range and difficulties in zooming down.	Bureaucracy, resource availability, delay in support to farmers

**DAFF: Department of Agriculture, Forestry and Fisheries*
***BFPA: Bethlehem Fire Protection Association*

It is evident that, if properly implemented, the policy frameworks and institutional establishments for Disaster Management will reduce vulnerability and lower the degree of exposure of wheat production to drought. If well implemented, this will have a positive effect on crop farmers. Box 3 presents the institutional policy arrangements for monitoring systems and warning systems, which farmers also need.

These pieces of legislation again indicate the strategy for Disaster Risk Reduction by the Government of the Republic of South Africa. Policy and institutional arrangements can influence the adaption of farming practices. Directly or otherwise farmers' adaption of mitigation measures is influenced by availability, or lack of, certain services as well as implementable policies that support the particular technology.

Adaptation strategies will only be successfully adopted if there is an enabling policy and institutional environment that assist in dealing with the barriers of adaption. Such guarantees are necessary to guarantee food security to the more vulnerable population, as well as guarantee that income losses will be smaller for farmers that are vulnerable (Cattaneo, et al., 2012). Therefore, some of the crucial adaptation strategies such as choosing improved cultivars, moving planting time according to the weather and optimizing fertilization usage need to be supported by the Government policies, research and technological interventions.

4.2.2 Disaster Mitigation Strategies in wheat production

Disaster management is a cycle that embraces prevention, mitigation, preparedness, response, recovery and rehabilitation. As a base for this study the principle contained in the diagram (Figure 4.1), developed by the United Nations International Strategy for Disaster Reduction (UN/ISDR, 2002) was used to explain the Disaster Risk Management environment. Figure 4.1 illustrates that the holistic nature of Disaster Risk Management is keeping sustainable production and development safe. The main elements of Disaster Risk Management is, risk assessment, awareness, reduction, response and recovery. These useful steps help to develop adaptation and mitigation strategies. The study focused on the mitigation strategies that were determined by the wheat farmers to mitigate the impact of climate change hazards by applying mitigation strategies such as early warning, farming practice adaptations, and risk transfer. We referred to early warning and risk transfer as external mitigation strategies because farmers have less control over. The farmers have control over farming practices, hence it is referred to as internal mitigation strategies. The external mitigation strategies of the Bethlehem farmers are presented in sub-subsection 4.2.2.1 because they are related to external influences, such as policy legislations and other stakeholders as indicated in the previous sub-section (sub-section 4.2.1).

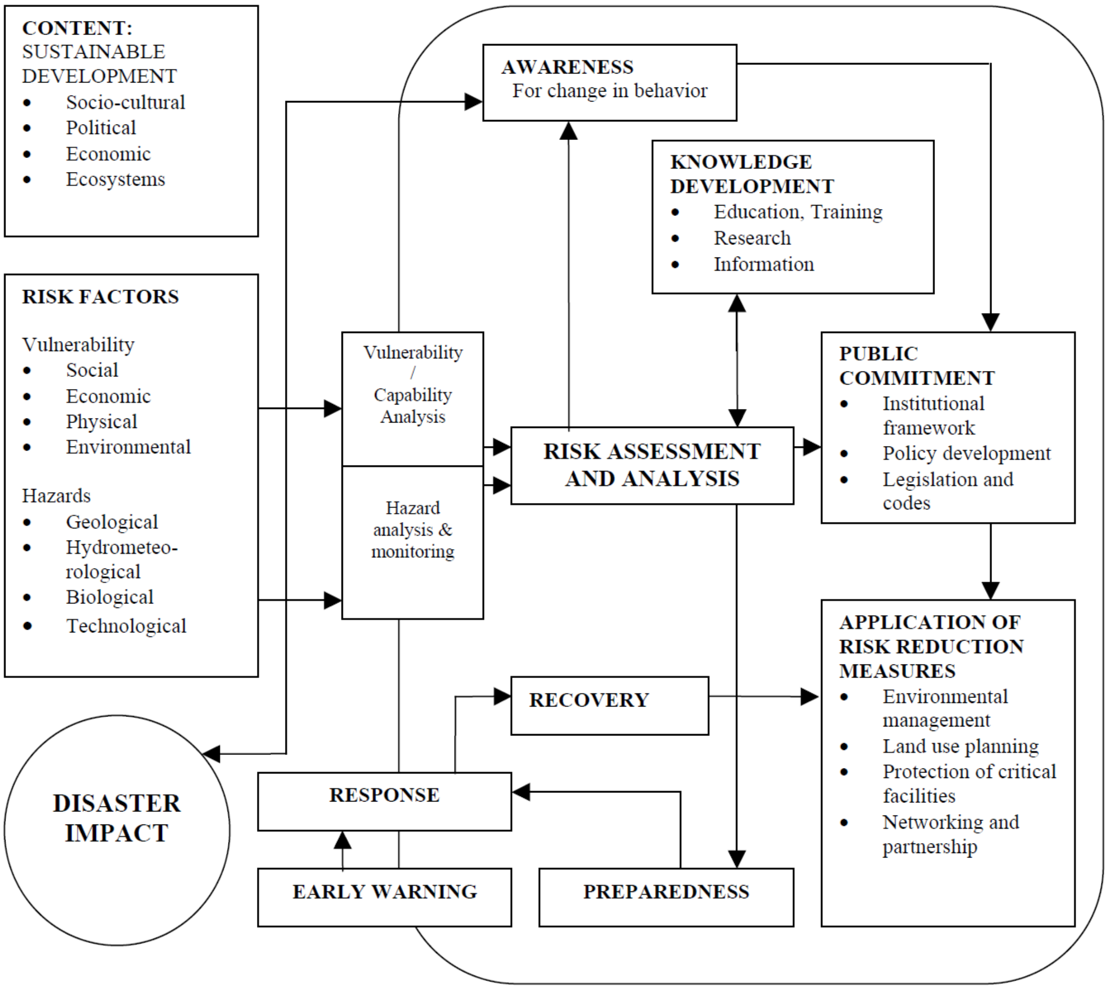

Figure 4.1 General principles for disaster risk management of United Nations (UN/ISDR, 2002)

4.2.2.1 Access to information and warning system

Access to weather information can serve as an early warning system that is needed as a mitigation to the impact of extreme weather conditions. The farmers' survey indicated that 93.3% of the sampled farmers have access to weather information and warning systems, while few (6.7%) do not have access, or may not be interested in the information. The Internet and the Television are the most common sources of weather information for farmers, while the less common sources are science publications and extension services (Figure 4.2). At times socio-economic status may influence the source of information that one can have access to on a daily basis. The weather information that comes from SAWS on a daily basis is easily accessed on the internet and television, though obviously it has difficulties to be specific for specific farming areas. With regard to extension services, it was expected that it will be among the most common types of warning systems, but it is increasingly acknowledged that the complexity of the capacity and structure presents challenges. Corresponding results about access to extension service was obtained by Benhin (2006) where access to the public extension services tested negative in all five models used. Most commercial wheat farmers accessed smart phones, it is possible to advance text messages and a demand-driven communication approach.

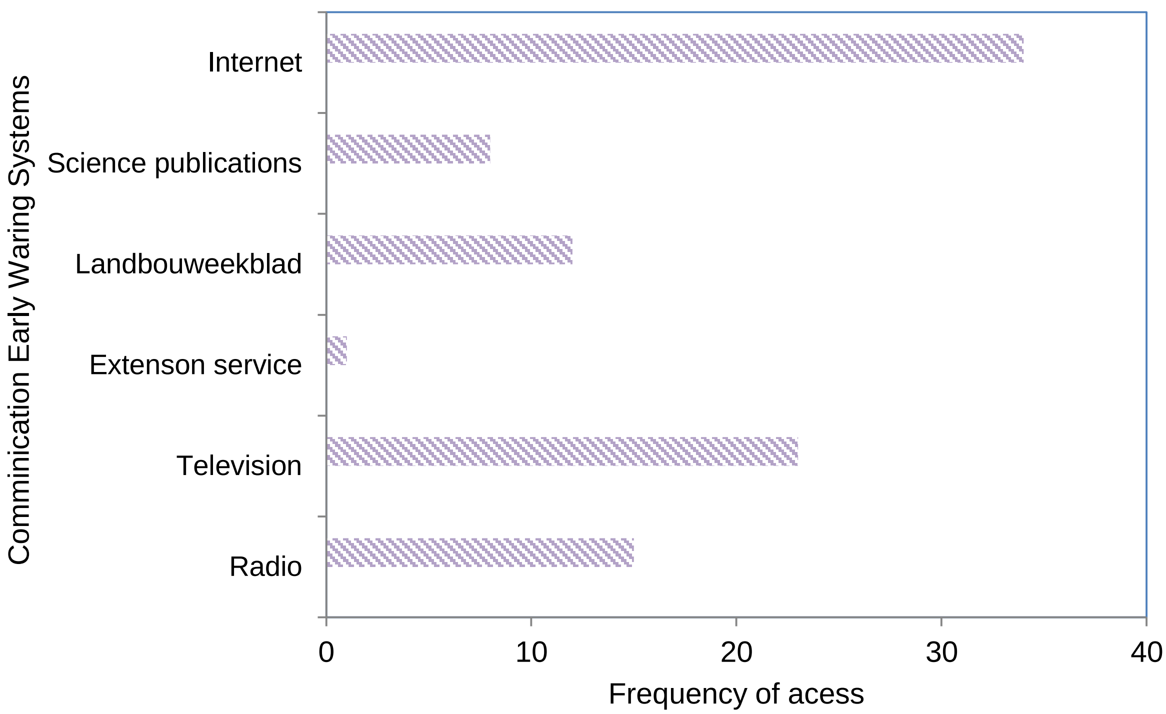

Figure 4.2 The frequency of farmer's access to early warning systems from the survey.

4.2.2.2 Risk transfer mechanism

When a loss of farm produce occurs as a result of the increased abnormal conditions of climate change or any other extreme weather conditions, some farmers have insurance for their crops, whereas others turn to the State Department Relief programs for assistance. The result shows that 40% of the sampled farmers stated that a risk transfer mechanism in the form of crop insurance in wheat production is a necessary mitigation measure (Table 4.2). The rest, nearly 60% of the sampled farmers, stated that a risk transfer mechanism in the form of crop insurance is unnecessary. The result show that the farmers stated that mitigating crop losses by state relief is necessary 58%, while 42% stated that it is unnecessary. This means that farmers see the need for state relief higher than private crop insurance as risk transfer mechanism. The most common risk transfer mechanism for commercial farmers is included in market-based transfer mechanisms (such as index-based insurance products) this is opening opportunities to expand the use of these types of innovative instruments during extreme weather conditions. This reduces exposure to the severity of extreme weather conditions as common mitigation strategies include irrigation, integrated pest management systems, and the adoption of risk-reducing technologies (such as improved seed varieties and fertilization) these are the preferences of the commercial farmers.

Table 4.2 Categorizing the risk transfer mechanisms by considering crop insurance and state relief funding

Risk transfer Mechanisms	Necessary		Not necessary	
	Rating	%	Rating	%
Crop Insurance	12	40.0%	18	60.0%
State Relief	23	76.6%	7	23.4%
Total	35	-	25	-
%	58.3%		41.7%	

These two risk transfer mechanisms (State relief and Crop insurance) showed various scales of usefulness on the range scale of ‘less useful’ to ‘extremely useful’ as shown in in Table 4.3. It can be seen that 77% of the sampled farmers’ rated that state relief is not useful, while only 40% undermined the use of crop insurance. Of the 23% who rate state relief mechanisms as useful, only 10% rate it as extremely useful while 10% rate it highly useful. Of the 60% who rate crop insurance useful, only 20% rate it highly useful while 30% rate it less useful. These results suggest that state relief though seen as not useful as crop insurance, it is deemed a necessary measure than crop insurance. This finding was discussed with other stakeholders who were interviewed and added their views and experiences.

Table 4.3 Farmers' ratings of crop insurance and state relief as risk transfer mechanisms

Rating	Crop insurance		State relief	
	Frequency	%	Frequency	%
Not useful	12	40%	23	77%
Less useful	9	30%	1	3%
Highly useful	6	20%	3	10%
Very useful	3	10%	0	0%
Extremely useful	0	0%	3	10%

4.2.2.3 Crop insurance

The inter-seasonal yield variation of cereal crop in South Africa became so high due to a shift in the cropping season, mainly because of uncertainties such as the amount of rainfall and duration. It is not only drought that causes poor crops and the resultant losses however the same applies when lower commodity prices occur and when rising input costs also substantially increase the risk of losses. Every wheat producer therefore, will have to think strategically, for instance use a "multi-risk insurance" that indicate that more than one risk is covered. Most multi-risk insurance claims in South Africa arise as a result of a change in climate such as drought. To the farmers, multi-peril was expensive and unprofitable, while to the insurance companies it was highly risky and less profitable too. Currently it is useful to ensure wheat crops against hail and frost damage. Hail is also becoming a challenge to insurance companies as it tends to occur in the critical stage of wheat crop development in the winter wheat growing areas. In some instances, when the crop grain reached full maturity, up to a 100% loss is possible if hail occurs (Wandrag, 2017). This confirms the results of the survey on farmers rating crop insurance, where of the 60% who rated crop insurance less to very useful, none of the respondents rated crop insurance as extremely useful (Table 4.3). The arguments of the wheat farmers on the usefulness of crop insurance need to be inclusive when considering both multi-risk insurance cover and multi-peril losses. During the interview with Wandrag in May 2017, Wandrag explained the difficulties and challenges of climate change and variability facing insurance industries as:

“As, extreme weather conditions such as drought, hail occurrence and flood which are closely intertwined with climate change can affect wheat harvest and poses a tougher business environment for the crop insurance industry. Many insurance industries use analysis of historical climate trends and used to predict recurrence of extreme weather conditions in order to determine premiums for insurance products. Wandrag emphasized that the difficulties and challenges are a business as usual between insurance industries and wheat farmers”.

Wandrag added, based on the legislation framework, that the Financial Services Board is the governing body of the insurance industry (Act, 1990 (Act No. 97 of 1990)) Therefore the insurance industry is governed as such. Thus, improving access to information, early warning systems and appropriate risk transfer mechanisms are an advantage for disaster mitigation strategies in wheat production.

4.2.2.4 State relief

The Disaster Management legislative framework is a guiding legislation in the undertaking of Disaster Management in South Africa, including financial support and subsidized input costs. In South Africa it is a slow process to have state relief funds issued to assist farmers after they have been affected by climate hazards. Prolonged expectation of financial assistance is a common phenomenon, due to the bureaucratic processes of the Government system, lack of resources and delays in program executions. This is seen very often with veld fire disasters, but it is also the case with crops and range land disasters. In the case of crop production, drought is always a major hazard and categorized as a slow setting disaster, changing farming operations is an attempt to mitigate it. This makes it a more complex matter for the state to resolve and to bring in relief funds to drought stricken farming communities. Because of all these factors and the availability of resources, the State relief funding may be seen as inefficient or not useful, as most farmers have alluded to during this survey. However, there is collaboration from the local Governmental institutions and organizations. For example Mr. Procter (in collaboration with the Disaster Management Unit) explained that there is a good local collaboration of the Bethlehem Fire Protection association (BFPA) as well as updates of warning messages from the South African Weather Services (SAWS). Mr. Procter also mentioned the dissemination processes of warning messages that flows from SAWS to the provinces and to various media houses, mainly Radio and Television. Mr. Procter says that provinces relay information to districts and to associations such as the BFPA which relay information via SMSs to its members (Procter, 2017).

4.3 Perception of farmers on climate change and adaptation measures

The second objective of this study was to explore commercial farmers' perception on climate change and the adaptation strategies of wheat production. Commercial wheat farmers' adaptation strategies to climate change have become necessary as climate change threatens food security through the occurrence of natural hazards such as drought, floods and fires, etc. The results in this study revealed that commercial wheat farmers assessed the adaptation and mitigation options practiced at their localities related to Disaster Risk Management systems and are implementing them.

According to Amadou et al. (2015) and Gadédjisso-Tossou (2015) perception, in addition to contribution by policies that help ensure food security, is a prerequisite for adaptation and implementing some mitigation measures. A greater influence of perception is indigenous knowledge of people. Perception is also determined by factors like age, experience, education, environment, and access to information on weather and climate. Bryan, et al. (2009) indicated that policies that can help to ensure food security requires an understanding of farmers' perception of climate change and the adaptation strategies adopted while creating conducive environment in mitigating hazards. In this study an attempt was made by interviewing commercial farmers to capture their perception on the effect of climate change in relation to their various factors, such as, age, farming experience, scale of farming, and access to information on weather and climate.

4.3.1 Farming experience of commercial wheat farmers interviewed

Table 4.4 depicts the experience of commercial wheat farmers, it ranges from as short as 3 years up to more than 40 years of experience. This reveals different views on the effect of climate change and the effect on production. The results show that 41% of the farmers have farming experience of 20 to 30 years, followed by 30% of farmers with experience of 30 to 40 years. These are the farmers that have a deeper understanding and enough knowledge about the effect of climate change during their years of farming. They have developed different adaptation measures according to different weather occurrences. Among many tactics flexibility is applied, those experienced commercial wheat farmers are taking adaptation to climate change as a planned strategy when the actions of mitigation leads to reduce risks and utilize new opportunities.

There is a smaller percentage of farmers (13%) with experience of more than 40 years, of which have mainly long traditional knowledge, these farmers have difficulties to cope with the new technology. However, this group of farmers showed a great sense of humor with the changing climatic factors and shifting of crop systems. Some of these experienced farmers have enough evidence to explain the natural resources degradation due to the effect of climate change, and showed their concern for sustainable farming systems in future wheat production. Among farmers interviewed, farmers with less experience of wheat farming have a relatively lower understanding of the effects of climate change, but they put a lot of effort into the increase of production and are injecting high investments. The general observation during the interviews was that the farmers with less years of experience, though they had some knowledge of climate change, had less knowledge and experience of recurring harsh climate conditions. Such farmers also appeared to have less knowledge of relevant adaptation measures, in particular climate related farming situations, and they are higher risk takers because they are implementing short term coping mechanisms to boost the wheat production. Some farmers are using their farming experience to learn about climate change impacts, and to seek adaptation measures from their previous experience. A 67 year old commercial farmer explained the following:

Changing farming practices, such as cultivars, planting dates, etc. takes an experienced farmer in order to make the proper decisions. This can be expected from the farmers who have more than 20 years of experience. Such farmers use their own farming adaptation strategies, but they are mainly aged farmers. He added that "it is time to upgrade the farming systems to be able to manage with new technology and to use information and warning systems which are crucial to tackle the effect of climate change.

Table 4.4 Years of farming experience of commercial wheat farmers

Years of farming experience	%	General observation from interview
< 10	3	Less knowledge and experience of change in climate
10 – 20	13	Gaining experience to recognize the changes in climate
20 – 30	41	Enough knowledge and experience for external occurrences
30 - 40	30	Long experience using farming adaptation strategies
>40	13	Thorough experience but mainly aged farmers

4.3.2 Farmers perception on climate change

The summary statistics indicate that about 97.1% of the respondents perceive that there have been some changes in the climate over the years (Table 4.5). There were at least 2.9% of the respondents who were not sure whether there was change or not. This is in line with other farmers' perceptions elsewhere, as indicated in literature (Amadou, et al., 2015; Cooper, et al., 2015; Gadédjisso-Tossou, 2015). When asked about their observations, particularly about temperature and rainfall, their observations were that there is an increase in temperatures (65.7%), followed by a decrease in rainfall (41%). The increase in temperature and decrease in rainfall are the most causal effects of yield reduction during the sensitive stages of the crop. However, some respondents had different views, for example 30.8% and 14.3% observed alterations in the time of rainfall and alterations in temperature ranges, respectively. On the other hand, only a few farmers (2.9%) responded that there is a decrease in temperature and an increase in the rainfall (2.6%) amount (Table 4.5). Farmers can observe all the climatic fluctuations through the previous years. Furthermore, it is difficult to realise the magnitude of changes that can have an influence in the crop systems, but some farmers seemed to recall all those extreme climatic events, for instance, most farmers easily recognized the recent drought years (2015/16) in South Africa with big wheat yield losses in the Free State, South Africa.

Table 4.5 Observation of the farmers in relation to climate change with the focus on temperatures and rainfall changes.

Climate change observations	Frequency of observation (%) in change main climatic parameters	
	Temperature	Rainfall
Increased	65.7	2.6
Altered range	14.3	25.6
Altered time	11.4	30.8
No change	2.9	0
Decrease	2.9	41.0
Don’t know	2.9	0

This result is consistent with the results of (Benhin, 2006) in the Free State where 75% of the respondents had noticed long-term changes in the climate in the province. Farmers expressed that the condition of the changes when frequently observed are, windy, dusty, drier and hotter temperatures, in particular during the summer seasons. Temperatures are increasing and the amount of rainfall has decreased. This is the common expressions by the farmers and also the reasons for decreasing yield in drought years. Some farmers recognize the erratic nature of the rainfall, and that it affects specific growth stages, in particular during the flowering and grain filling stages. There has also been an increase in the occurrence of droughts and the timing of the rainfall fluctuates from year to year (Benhin, 2006). There is evidence of rainfall trends suggesting a moderate decrease in the annual rain fall, with high inter-annual rainfall variability since the late 1960s. Other strong evidence, based on the analysis of minimum and maximum temperature trends, indicates that the temperature in the region is increasing (Kruger & Shongwe, 2004; Jury, 2013; Fauchereau, et al., 2003; Blignaut, et al., 2009).

4.3.3 Farmers adaptation measures

Climate changes have led to some shifts in the agricultural season. This was evident in Bethlehem as confirmed by the survey farmers and the reviewed literature about the Free State province. Farmers need to adapt to such a shift in season either through locally developed experiences or cope with warnings issued from a variety of institutes. Results from the survey show that (Figure 4.3), on a relative frequency of occurrence, change in planting date is the most common observed adaptation measure of the sampled farmers (23.6%), while increased amounts of fertilizers are the least common adaptation measure observed (0.8%). From the result the second adaptation measure commonly practiced by farmers is changing the crop (22%) and some farmers change the wheat cultivar (15.7%). These results are in agreement with the reviewed literature that shows that the most popular adaptations are changing cultivars and moving planting dates, because farmers consider such adaptation measures as cheap to adopt (Abid, et al., 2015; Amadou, et al., 2015; Apata, 2011; Gadédjisso-Tossou, 2015). Adaptation Studies show that in Kenya and South Africa it was found that yield decrease was less when farmers adopted the appropriate sowing date as a management option to mitigate the impact of climate change (Waha, et al., 2012). Farmers are alert enough in many cases to choose the appropriate planting dates according to seasonal variations, however these adaptation measures need to be supported by some advisories.

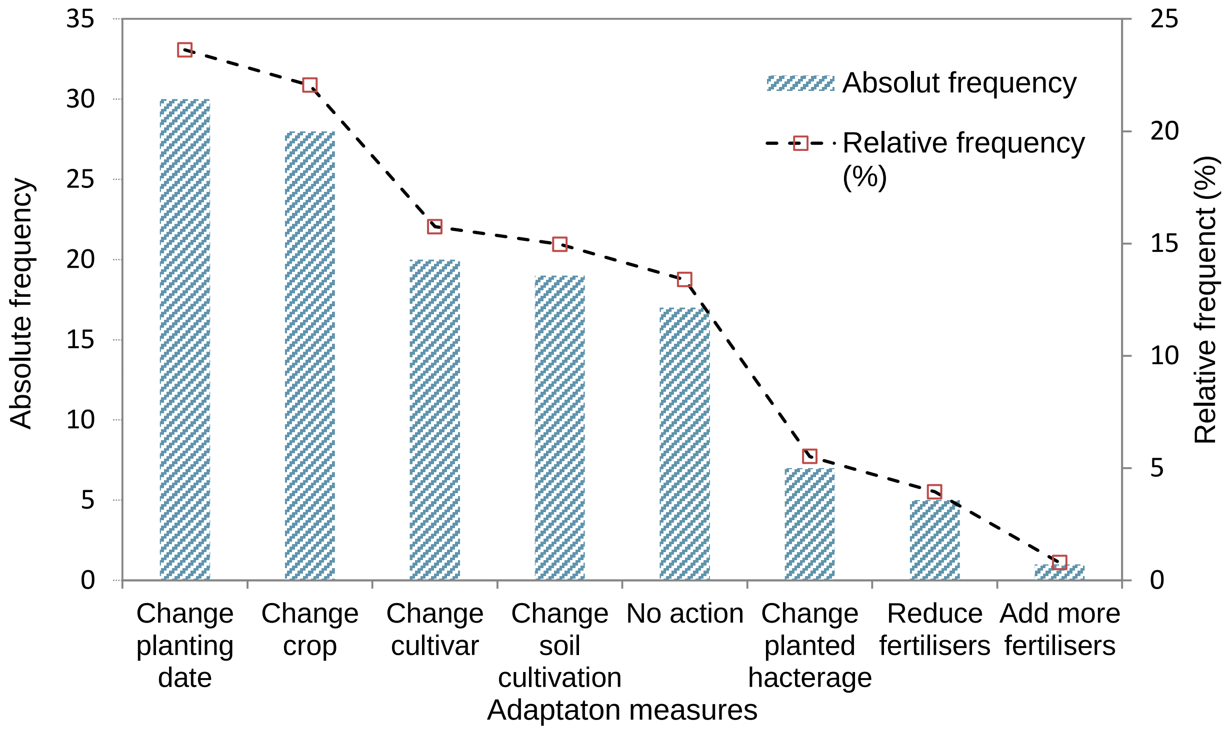

Figure 4.3 Various adaptation measures to climate change implemented by commercial farmers.

Benhin (2006) stated that some of the adjustments made by farmers in their operations include changes in the planting dates of some crops, planting crops with a shorter growing period such as cabbage, and planting short season maize. Benhin (2006) has also stated that with the increasing uncertainty of long dry-spells and occasionally heavier rainfall concentrated in shorter periods, this is a better measure. For example one farmer explained as follows:

As recent rainfall conditions started late during the season, the previous early planting in September in Bethlehem shifted by 3-4 weeks (start in October) and showed irregularities in some areas. This condition forced farmers to start planting later with short maturing cultivars. Another framers stated that; *in addition to delaying the start of the planting, some large-scale farmers have also opted to take lower risks by reducing their cropping areas to manageable sizes.* The wheat farmers also reduced the planting areas in South Africa for the past fifteen years as depicted in Figure 2.2, the trend showing a sharp decline in the areas planted under wheat. During the survey, farmers explained the main reason for lowering the wheat hectares in the Bethlehem area is due to climate change and farmers attempting to minimize the risk.

4.3.3.1 Cultivar types with planting and harvesting time

The results in Table 4.6 depicted that some of the wheat cultivars that are commonly used in the Eastern Free State are Elands, PAN 3120, PAN 3164, SST 356 and Matlabas. Other cultivars such as Hugenoot and families of SST and PAN cultivars were also mentioned by many farmers during the survey. The most popular cultivar used, according to the results, is Elands with a 40% frequency. When treated individual cultivars in this analysis, the ‘others’ group of cultivars used showed very low (1 - 3%) and in total the other cultivars was about 17%, but this still indicate that farmers use a variety of cultivars. Farmers in the survey illustrated that the use of various cultivars are evidence of the availability of a variety of cultivars in the market places. The diversification and availability of the wheat cultivars in South Africa is reported in the small grain ARC-SGI (2013) report.

In the Eastern Free State wheat planting time ranges from the 2nd week of May to the 2nd week of August. The dryland wheat planting is concentrated mainly in June and July. Planting time ranges according to cultivars type (ARC-SGI, 2013). Accordingly, harvest time for wheat begins in December in the dryland cooler Free State areas. Table 4.6 shows that all surveyed farmers’ plant within the usual planting window.

The results show that most farmers’ plant in June and July and harvest starts in December and according to the maturity of cultivars extends up to January. In this survey results revealed that the majority of the farmers who harvest in January are those who plant the Elands cultivar. This indicated that the Eland cultivar is one of the medium to long maturing cultivars that need a longer duration to complete the grain filling stages. In certain instances harvesting of wheat is hampered by incessant rainfall during December. This may cause farmers to choose cultivars such as Elands, so that they can harvest later, in January, when there is less chance of rainfall. Certain cultivars are susceptible to pre-harvest sprouting, their harvesting cannot be delayed. The

Elands cultivar is one of the included cultivars, in simulating yields in this study, to manipulate changing planting dates.

Table 4.6 Wheat cultivars, planting time and harvesting time adopted by sampled farmers in the Bethlehem area and Eastern Free State

Cultivar type	Frequency (%)	No. Farmers planted & harvested (month)					Remarks
		Planting			Harvesting		
		Jun	Jul	Aug	Dec	Jan	
Elands	40	7	9	0	8	10	Mid maturing cul.
PAN 3120/3164	17	2	5	0	6	2	Mid maturing cul.
SST 356	14	1	4	0	2	3	Early maturing cul.
Matlabas	12	5	2	0	6	0	Mid maturing cul.
Others	17	4	2	1	5	2	Wide range of cul.

4.3.3.2 Range of area planted and yield

Figure 4.4a shows that 60% of the sampled farmers' wheat planting ranges from 100 to 200 ha over five years, while 13% ranges between 200 and 300 ha. At least the same number of farmers (13%) has planted more than 300 ha over the past 5 years. Those farmers who planted between 1 and 100 ha are 14% of the sample, wheat production is a secondary or tertiary farming practice. It was observed that most farmers have reduced the areas planted under wheat, especially under dryland conditions in the Eastern Free State. Thus, in general, dryland farming reveals a discrepancy from what the result showed, where the area planted did not count among the adapted measures.

With regard to the wheat yield over five years, from the farmer's survey, it is indicated that 80% of the sampled farmers obtained less than 2 ton ha^{-1} where 43% of farmers obtained less than 1.5 ton ha^{1}, and 37% obtained between 1.5 to 2 ton ha^{-1} (Figure 4.4b). With only a few respondents (20%) of the sampled farmers reported more than 2.5 ton ha^{1}, it shows that many farmers in Bethlehem have seen their wheat production declining due to different external factors, including climate change. This result is in line with the literature that shows that in South Africa wheat production has been declining since 1998, as seen in Figure 2.3. This result is also in agreement with the fact that in Free State province wheat production has been declining since 2011as seen in Figure 4.9, mainly due to unfavorable weather conditions and low or inappropriate adaptation measures. The other main factor is also declining planted areas (since 2003), as farmers shift to other crops to cope with climate change and minimize the risk factors. In general, the decline in areas planted under wheat resulted in lowering the country's wheat production (USDA, 2017). The survey result provided a highlight on how the wheat production diminished, and to what extent this influenced the overall wheat production of the country. It indicates that the country's wheat production need to be increased, the productivity intensified and irrigated wheat production must be supported.

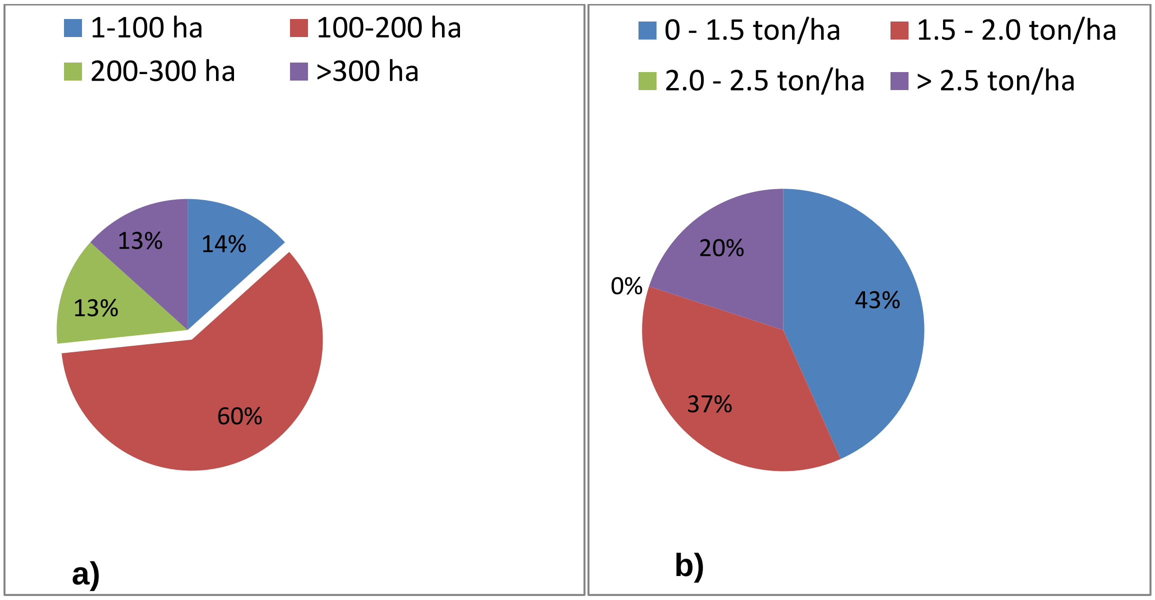

Figure 4.4 Range of planted area under wheat (ha) and obtained yield (t/ha) over 5 years from 30 farmers surveyed in Bethelhem. **a)** Average area planted. **b)** Average yield obtained.

Farmers in Bethlehem have indicated that they have a perception that there has been a change in climate factors. The temperature, which model simulations in other studies have attested to, impacted on wheat production and is observed by farmers as increasing, and altering in ranges. The next section presents the results of the crop model application.

4.4 Crop model application

The third objective of this study was to assess different management options (such as planting time, improved cultivars, and fertilization rates) as climate change adaptation measures on wheat yields, using crop model simulations. This section presents the assessment of the three most common adaptation measures of climate change indicated by the sampled wheat farmers. Change of crop type was excluded in this simulation, although it was among the most commonly used adaptation measures for two reasons. First, it is a known practice that farmers will change to other crops that will withstand the effect of poor rainfall patterns, especially if such crops attract good market prices, but the challenge is that this may compromise food security in some instances. Thus, an attempt in this study was made to find appropriate options and management practices to contribute to food security. Secondly, winter wheat is one of the highest economic important crops and there is no alternative winter crop is of high economic importance as wheat in South Africa.

The DSSAT and other models have evolved with research and the scientific needs to remain useful tools for use in today's challenging climate change in agriculture (Jones, et al., 2003; Nkulumo, et al., 2013; Ewert, et al., 2014). In this study, an attempt was made to incorporate the crop model application (DSSAT) to simulate three planting dates, three cultivars and three levels of Nitrogen fertilization management under dryland conditions.

4.4.1 Model performance calibration

Model calibration is the adjustment of parameters so that simulated values compare well with observed data. The genetic coefficients that influence the occurrence of developmental stages in the model are used in calibration of the model. The genetic coefficients that influence the occurrence of developmental stages in the model are used in calibration of the model. The DSSAT wheat model was calibrated considering locations, varieties and common management practices as documented by Rezzoug, et al. (2008). The genetic coefficients of cultivars Elands, SST 124 and Betta-DN South Africa were used as a coefficient for DSSAT4.6. Table 4.7 shows the values of the seven DSSAT genetic co-efficient for the three wheat genotypes (ARC-SGI, 2013).

Table 4.7 Genetic coefficients fitted to calibrate DSSAT model for the three cultivars

Cultivars	Coefficients						
	P1V	P1D	P5	G1	G2	G3	PHINT
Elands	55	150	600	30	35	5.0	60
SST 124	32	78	532	21	29	2.4	60
Betta-DN	43	74	484	25	30	2.4	60

P1V = Days optimum vernalizing temperature require for vernalisation (days)
P1D = Photoperiod response (% reduction in rate/10h drop in pp)
P5 = Grain filling (excluding lack) phase duration (^{0}cd)
G1 = Kernel number per unit canopy weight at anthesis (#/g)
G2 = Standard kernel size under optimum conditions (mg)
G3 = Standard non stressed mature tiller wt (including grain) (g dwt)
PHINT = Interval between successive leaf tip appearance (^{0}cd)

4.4.2 Model evaluation

The DSSAT wheat model evaluation was performed for two cultivars, using both early and late planting dates (Figure 4.5). The data is average values of grain yield obtained under common management practices in the Bethlehem region, including aspects such as; cultivar, planting date, growth analysis, fertilizer application, harvesting date, and final yield components. Results indicate that DSSAT Model is an adequate tool to simulate wheat growth, particularly in evaluating relative changes in crop yield in relation to various management practices. In general, the model performance showed reasonable R^2 and RMSE values.

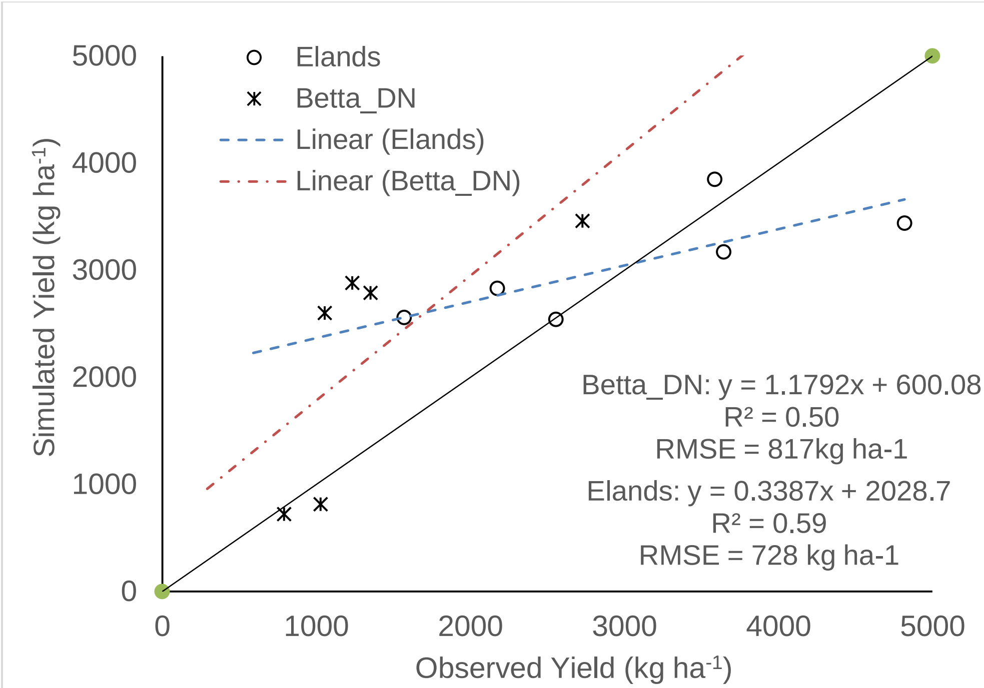

Figure 4.5 Model performance using validation values simulated against observed yield (kg ha^{-1}) for two different cultivars for both early planning and late planting

4.4.3 Yield simulation

4.4.3.1 Early planting

During early planting dates the cumulative probability curves of the simulated wheat yields for three different cultivars under three fertilization levels (25, 50 & 75 N kg ha^{-1}) are shown in Figure 4.6. In all three cultivars, the higher N fertilization management showed higher yields compared to low N applications. The Eland cultivar gave better yields compared to the other two cultivars. Figure 4.6a shows that at a higher fertilizer management level (75kg N ha^{-1}), the Eland cultivar has a 70% probability of obtaining up to 1.1 t ha^{-1}, which is a higher probable yield than 0.6 t ha^{-1} achieved by both the SST 124 and Betta-DN cultivars. At a medium level of fertilizer management of 50 kg N ha^{-1} the SST 124 and Betta-DN will only obtain 0.5 t ha^{-1} while the Eland cultivar obtained almost 1.0 t ha-1 yields in a long term simulation. Figure 4.6b&c shows no yield differences between the SST 124 and Betta-DN cultivars at 30% probability of non-exceedance at medium and high fertilizer management applications. Both cultivars are not exceeding 0.5 t ha^{-1}. However, at the same level of probability under low fertilizer management (25kg N ha^{-1}) Betta-DN not exceed 0.4 t ha^{-1} while SST 124 obtained up to 0.3 t ha^{-1}. For the SST 124 and Betta-DN cultivars, using low fertilization levels of only 25 kg ha-1, shows a low yield near crop failure at 80% of the cumulative probability level, however the simulated yield doubled with increasing levels of fertilization. In the case of the Elands cultivar, there is a 20% probability of obtaining 775 – 900 kg ha-1 when increasing the level of fertilization. Thus the simulation results depicted the higher risk of crop failure in using cultivars such as SST 124 and Betta-DN. Using the Elands cultivar in the Bethlehem region, in particular with no or low fertilization management, had better results. This management practice may assist a small scale farmer with limited resources, he can apply less fertilizer during dry years as the situation promotes an on-farm decision for low level input situations.

During early planting of the Elands cultivar, with the addition of fertilization scenarios, the simulation result found that there is a 20% chance of obtaining the highest yield of 3.2 t ha^{-1} and 3.5 t ha^{-1} for 50 and 75 kg of N fertilization, respectively. This indicates that by using improved cultivars, with the fertilizer application management, a wide range of yields could be expected in a good rainy year. Farmers need to consider different tactical approaches when making decisions according to the rainfall amount and the distribution of available resources. In this targeted wheat yield simulation under different scenarios, any decision maker should be able to increase soil water productivity and improve crop water efficiency by using appropriate cultivars.

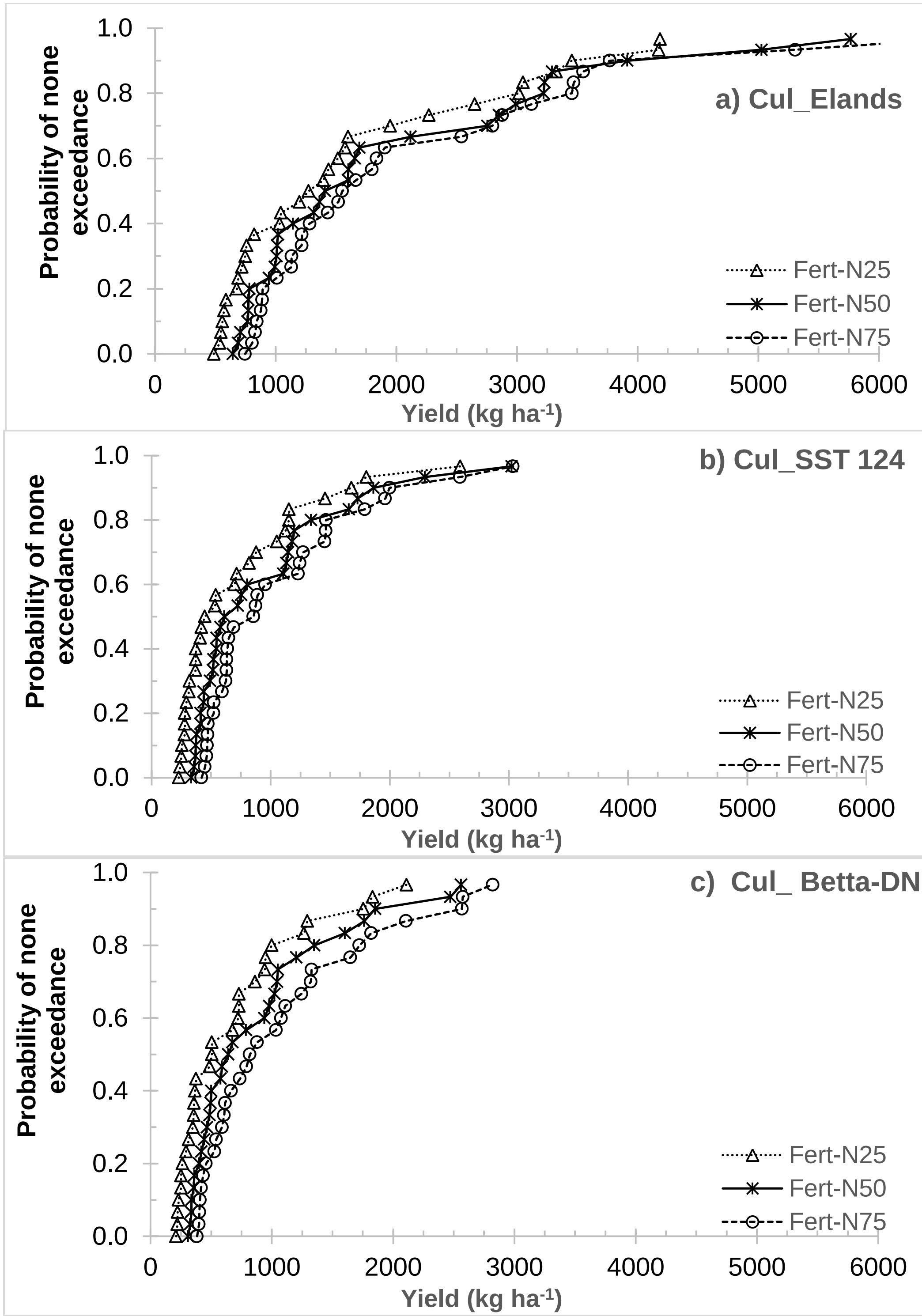

Figure 4.6 Simulated yield under three fertilization levels for early planting dates from 1980-2009 for cultivars: **a)** Elands **b)** SST 124 & **c)** Betta-DN

4.4.3.2 Late planting

For late planting, all the cultivars with fertilization at planting had significant differences in the cumulative probability curve between different levels of fertilization (Figure 4.7). The results show a probability of 20% that the Eland cultivar gave 3.6, 4.7 and 5.6 t ha^{-1} during years of good rain for 25, 50 and 75 N kg ha^{-1} application, respectively (Figure 4.7a). Whilst the yields remain below 0.30, 0.36 and 0.39 t ha^{-1} for the Betta-DN cultivar when the fertilization application increased from 25 – 75 kg ha^{-1} (Figure 4.7b&c). However, the SST 124 cultivar at 20% of the cumulative probability level during a good rainy season, yields are in the range of 2.0 – 3.1 t ha^{-1}. In late planting there is about an 80% chance to obtain 1.5 t ha^{-1} yields by using the Eland cultivar, while there is a high chance for crop failure if the farmers use both the SST 124 and Betta-DN cultivars under various levels of fertilization. Thus, with increased N fertilization, the Elands cultivar gave a better yield compared to the other cultivars when practicing late sowing dates (Figure 4.7a-c).

It is suggested that increased variations in rainfall, temperature, length of rainfall season, on-set of rain and yield would impact the definition of appropriate adaptation strategies for improved cultivars for better yield. For example, by choosing cultivars like Elands and planting late, the farmer has a high chance (>70%) of obtaining 1.8 t ha^{-1} with low levels of fertilizer (25kg N ha^{-1}) whilst planting early with the same practice, there is only a chance to obtain up to 1.3 t ha^{-1}. For a small scale farmer, with limited resources, applying less fertilizer is a common practice, therefore this strategy could assist in deciding about low level input situations. When comparing early planting, it is evident that climate change contributed more than fertilizer levels towards yields obtained during late planting. Changing to cultivars such as Eland combined with late planting and medium levels of fertilizer management seems to be a solution to mitigate yield loss due to climate variability, where yield of 2.5 t ha^{-1} is possible with a 70% probability. There are less than 50% chances of significant yield benefits from fertilizer increases when planting late with the tested cultivars and fertilizer levels.

It is evident that this model has proven that food security can be addressed by using decision tools such as the DSSAT. Tools that successfully determine that the Eland cultivar has a 100% chance of yielding as high as 0.5 t ha^{-1} under stringent resources such as fertilizer. While disregarding economic viability of such levels of yield under commercial farming, 0.5 t ha^{-1} can be a solution to food insecurity in other socio-economic conditions that prevail in this country.

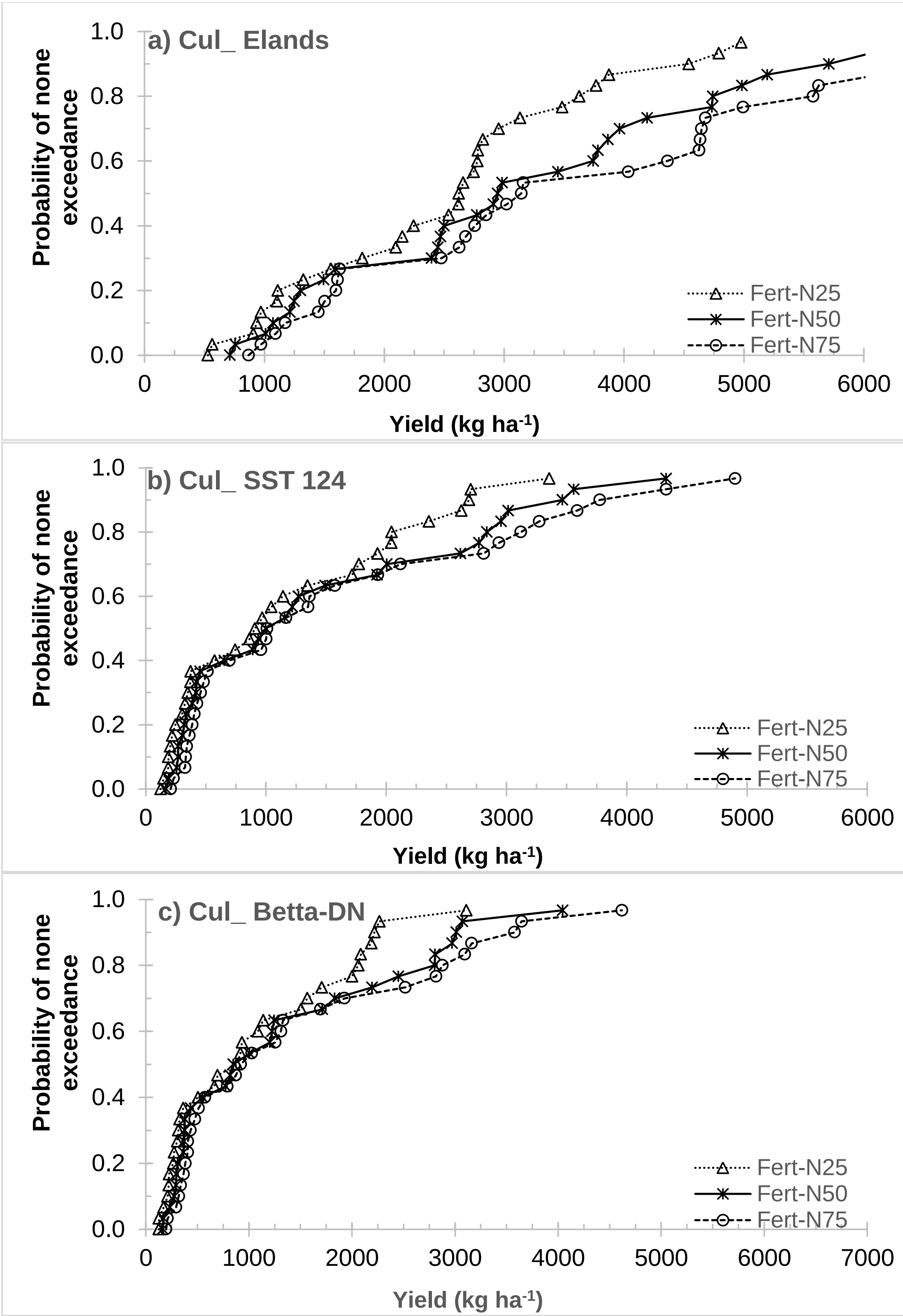

Figure 4.7 Simulated yield under three fertilization levels for late planting dates from 1980-2009 for cultivars: **a)** Elands **b)** SST 124 & **c)** Betta-DN

4.4.4 Summary Simulation

The ten year mean simulated wheat yield with various fertilizer application levels at two planting dates is summarized in Table 4.8. In both planting dates, the addition of various levels of N fertilization has increased the yield. The long-term simulation yield averaged over 10 year's shows that there were important variations across cultivars. The variations are different between climatic years of an average of 10 years, implying the prominent effect of climate change since 1980. In general, the Elands cultivar has performed well under all fertilizer management levels and in the consecutive 10 years averaged well. However from Table 4.8 it is evident that the average simulated yields in both planting windows are declining from the early years (1980-1990) compared to the intermediate years (1991-2000) and the later years (2001-2009). This shows that the effect of climate change on grain yields and the response is more pronounced on those cultivars not performing well, such as SST 124 and Betta-DN.

Furthermore, the planting events also played a significant role in improving the yield under various fertilizer management options. In the 10 year average simulated yields, the Elands cultivar performed higher during late planting dates that ranges from 2.8 - 4.1 t ha-1 compared to early planting dates at a range of 1.7-2.6 with increased fertilization management. In the early planting simulations, the average yield also showed similar trends of decreasing from early simulated years to late simulated years but the average was much lower compared to the late sowing dates. On the other hand, of the other two cultivars, SST 124 achieved the lowest (1.0 t ha^{-1}). Elands and Betta-DN seem to respond well to higher fertilizer applications, while SST 124 responded better to lower fertilizer applications.

The capacity of the DSSAT to reproduce the response of three wheat cultivars to inter-decadal climate variability was evaluated by different tactical strategies for farming decisions. As illustrated in table 4.8 there were slight differences in the simulated grain yields between the 3 decades, this implies that the effect of climate change in grain yield does show. The 1980 -1990 decade was more favorable, the highest and lowest grain yields were again achieved by cultivars Eland and Betta-DN, with values of 2.6

and 1.2 t ha-1, respectively. The 2001-2009 decade was unfavorable with the lowest yield of 0.6 t ha^{-1} achieved by the Betta-DN cultivar. The Eland cultivar achieved the highest grain yield of 1.7 t ha^{-1}.

The model shows all three cultivars performing better on late planting dates compared to early planting dates. The Eland cultivar performed higher than all the other cultivars under all the fertilizer management levels. The highest grain yield was 3.4 t ha^{-1} for Elands, SST 124 and Betta DN were 1.5 and 1.4 tha^{-1} respectively under higher fertilizer management levels (75kg Nha^{-1}). The Eland cultivar performed higher under low fertilizer management levels (25kg Nha^{-1}) with yields of 2.4 tha^{-1} followed by 1.1 and 1.0 t ha^{-1} of SST 124 and Betta-DN respectively.

Late planting combined with medium fertilizer levels (50kg Nha^{-1}) surpasses early planting combined with 75kg Nha^{-1} in yields of 32, 26 and 17% for Eland, SST-124 and Betta-DN, respectively. From the study in East Africa (Ethiopia using the DSSAT model simulation), the planting date windows has proven to be among the most important factors in determining yield variations under various fertilization levels (Abayisenga, 2015). The model results indicate that changing cultivars can mitigate certain weather conditions associated with different years or seasons as Asseng, et al. (2015) concluded that cultivars have different mechanisms of tolerating environmental conditions. From this research simulation results one can suggest that an appropriate combination of planting dates, selection of cultivar and recommended fertilization management according to the specific season may result in higher productivity with reduced climatic risk factors.

Table 4.8 Summary of simulated yield (kg ha^{-1}) for three cultivars with three fertilizer applications under early and late planting dates for the period of 1980-1990, 1991-2000 and 2001-2009

Cultivar Type		**Cultivar_ Elands**			**Cultivar_SST 124**			**Cultivar_Betta DN**		
Planting Date	**Years**	**Fert-N25**	**Fert-N50**	**Fert-N75**	**Fert-N25**	**Fert-N50**	**Fert-N75**	**Fert-N25**	**Fert-N50**	**Fert-N75**
Early Planting	1980-1990	1778.9 (1310.4)*	2297.8 (1712.2)	2581.5 (1881.1)	833.2 (726.9)	1080.4 (850.8)	1247.5 (855.6)	787.0 (635.9)	1092.5 (761.3)	1228.5 (748.2)
	1991-2000	1457.3 (1053.9)	1669.2 (1082.2)	1797.1 (1098.1)	706.5 (548.1)	890.6 (602.5)	999.1 (636.3)	683.4 (526.4)	811.5 (613.9)	901.0 (649.8)
	2001-2009	1462.2 (947.0)	1627.6 (952.0)	1698.0 (875.5)	580.3 (301.1)	723.8 (313.4)	828.3 (320.1)	555.9 (268.2)	691.7 (301.6)	993.7 (683.0)
	Mean Std	**1566.1 184.3**	**1864.9 375.5**	**2025.5 484.0**	**706.7 126.4**	**898.3 178.4**	**1025.0 210.8**	**675.4 115.8**	**865.2 205.8**	**1041.1 168.8**
Late Planting	1980-1990	2815.3 (1291.9)	3536.4 (1657.3)	4081.1 (2002.7)	1403.8 (1096.8)	1815.0 (1489.7)	2057.0 (1733.2)	1274.3 (983.3)	1634.8 (1342.5)	1862.8 (1570.1)
	1991-2000	2279.5 (1178.4)	2938.0 (1650.3)	3319.4 (1869.3)	928.5 (882.9)	1115.3 (1020.0)	1203.1 (1040.5)	814.8 (729.4)	1038.5 (950.8)	1116.1 (955.1)
	2001-2009	2066.2 (1147.3)	2485.4 (1442.0)	2798.9 (1717.5)	1011.3 (739.3)	1208.5 (923.6)	1371.3 (1043.3)	910.6 (676.9)	1106.6 (868.7)	1202.0 (977.5)
	Mean Std	**2387.0 385.9**	**2986.6 527.2**	**3399.8 644.9**	**1114.6 253.9**	**1379.6 379.9**	**1525.8 463.6**	**999.9 242.4**	**1260.0 326.4**	**1393.6 408.6**
Overall Mean		**1976.6**	**2425.7**	**2712.7**	**910.6**	**1138.9**	**1275.4**	**837.7**	**1062.6**	**1217.4**

*NB: * the brackets denote the standard deviations value for each time series and all the units are in kg ha^{-1}*

4.5 Preliminary Agricultural Decision Support Tool (DST)

The fourth and last objective of this study is to develop preliminary recommendations and tools as agricultural support decision systems for commercial wheat farmers to assist in mitigating the effect of climate change on wheat yield.

A preliminary tool for the decision support system (DST) were developed by evaluating simulated yield variations under the investigation of selected risk transfer mechanisms through assessing farmer's perceptions (Figure 4.8). As DST, the ability of the Crop Growth Model (CGM) simulation using the DSSAT were employed under various different N fertilizer applications and possible sowing windows for potential wheat cultivation in Bethlehem. It is generally assumed that wheat production, by identifying the best cultivars at optimum N fertilization and selection sowing dates, is expected to give high yields across wide ranges of year to year climatic variations. Furthermore, possible farmers' choices are also generally based on the long-term mean performance of the simulated yield (e.g., decadal year's average) and the statistical standard deviation around the mean values (Table 4.8) were computed. As part of the decision making options, the technical advisors (researchers and extension officers) expected to identify the best cultivar to be used at optimum N fertilizer and sowing windows for the specific location, soil, climate and commonly used crop management practices. In considering the DST for each particular season, wheat farmers in semi-arid areas expected to select high yielding cultivars with appropriate choices for optimum N fertilization and sowing dates.

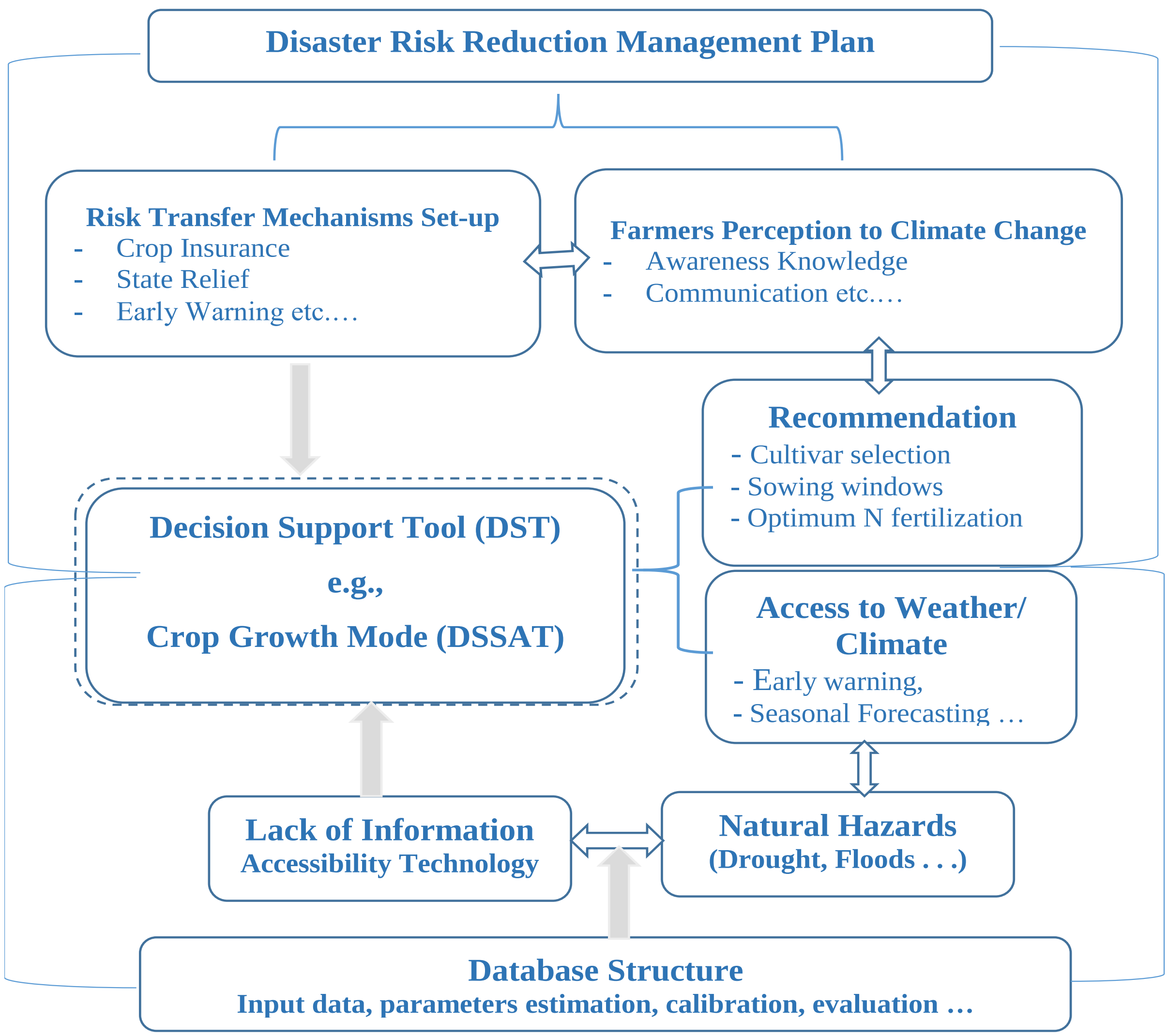

Figure 4.8 Schematic representation for preliminary recommndation as Decision Support Tool (DST) as input both the disaster risk management and database structure

Dealing with risk and climate uncertainty is a common phenomenon in semi-arid areas, hence farmers need assistance to prepare accordingly for possible future climate events in order to avoid losses. The IPCC, in its recent report, has stressed the importance of understanding crop yield variations, farmer's perceptions on the impact of climate change and available tools for making on-farm decisions. In this study, with the focus on wheat yield in the Bethlehem region, a Disaster Risk Reduction Management plan to risk transfer mechanisms are presented, these are access to crop insurance and the provision of state relief.

Access to weather information can serve as an early warning system needed to mitigate the impact of extreme weather conditions. The farmers' survey indicated 93.3% of the sampled farmers have access to weather information and warning systems while few farmers (6.7%) do not have access or may not be interested in the information. Sources of weather information, most commonly accessed, are the internet and television (Figure 4.2). It is commonly known that access to information advances ones knowledge. The weather information that comes from SAWS on a daily basis informs the farmers of climate change. At times, socio-economic factors may influence the source of information that one have access to.

Adaptation strategies by farmers to climate change is also affected by the social factors mentioned. Adaptation strategies do require enabling policies and institutional systems to be successfully adopted, advisories communicated from researchers and agricultural extension officers. Therefore there is a possibility that the risk transfer mechanisms will assist in dealing with barriers to adaption during disasters. Gadédjisso-Tossou (2015) found that 42% of the farmers who indicated that they perceived a change in climate showed low adaptation rates during disaster years. Abid et al. (2015) further found a lack of money was among the reasons for non adaptation. In this study it is indicated that the common adaptation strategies by wheat farmers in Bethlehem are changing the planting date, changing crops, and changing cultivars.

The result revealed that under a variation of climatic factors, the simulated outputs may support the adoption of decision making tools for wheat farmers. Thus, this simple DST may help wheat growers with the selection of a specific management over various N fertilizations and weather constraints to identify the best cultivars to be used in each case. Nevertheless, since the response of cultivars depend on yearly climatic variations, there should be some information (e.g., ENSO/SOI episodes) to be able to identify choices of risk transfer mechanisms. For example, in this study two risk transfer mechanisms were evaluated when the growing season was abnormal, such as crop insurance used as a contingency plan and / or state relief during extreme weather conditions causing a total crop failure. At a time when losses occur or extended abnormal weather conditions prevail or extreme weather episodes occur, up to 40% of the respondents rated risk transfer mechanisms as an essential prerequisite for risk reduction (Table 4.2).

One of the respondents stated that "*farmers using low input crop management is a normal practice in multiple drought events*." This is evident as the climatic conditions change, farmers consider crop insurance or state relief support as risk transfer mechanisms. However, the integration of risk transfer mechanisms to the model evolution is rarely done in the literature, the model is a support as a decision making tool. The results obtained for wheat yield show that the crop growth model (DSSAT) has the potential to predict an average yield run for a wide range of environments, and more specific for wheat growing regions in South Africa (e.g., as in the case of the Bethlehem district). The integration of farmer's perceptions, access to weather information and risk transfer mechanisms in crop model outputs could be highly supportive.

4.6 Discussion of Results

Winter wheat production in Bethlehem is reliant on cold winter temperatures and cooler spring temperatures. Vernalization is an important contributor to yield components and eventually grain yield. Wheat plants need to be exposed to cold temperatures for 2 to 3 weeks, some up to six weeks. The exact temperatures and duration varies according to cultivars (Lindeque, 2008). It is observed by farmers in this study that the temperature in Bethlehem is increasing. The hazard thereof is that warmer than average winter temperatures may reduce the duration of vernalization, negatively affecting the yield component and therefore reducing grain yield. This is in line with Asseng et al. (2015) which concluded that for each ^{o}C increase in global mean temperature, there is a reduction in global wheat grain production of about 6%. Management practices that will reduce the risk of and the impact of such hazards are proper cultivar choice and optimum planting date. A good fertilizer management program, guided by a proper soil nutrient analysis will also guard against yield drops.

Alteration in temperature regimes and increase in temperature, as observed by sampled farmers in Bethlehem, may also suggest that there are early warmer temperatures that occur during the wheat season. Wheat plants require warmer temperatures to advance to anthesis. The amount and duration of exposure also vary according to cultivars. Anthesis is the flowering stage and flowers develop into grain formation, which is an important yield component. Early warmer temperatures advance anthesis dates and shorten vegetative periods, thus decreasing the number of days during which plants could intercept light for photosynthesis, with consequent reductions in biomass and grain yields (Asseng, et al., 2015). Temperature ranges of 5 to 25 ^{o}C are suitable for winter wheat in South Africa.

According to the sampled farmer's observations, the rainfall in the season has also altered, and the amount has decreased. Decrease in amounts and alterations in rainfall patterns are another hazard of climate change that threatens wheat production in the Bethlehem area. The observation by farmers and the climate models that predict an ever evolving shift in rainfall patterns imply that there is a reduction in wheat production. Bethlehem farmers' observation of wheat yield reduction trends are confirmed by yield forecasts of the Crop Estimation Committee (CEC) from 2011 to 2016 as shown in Figure 4.9.

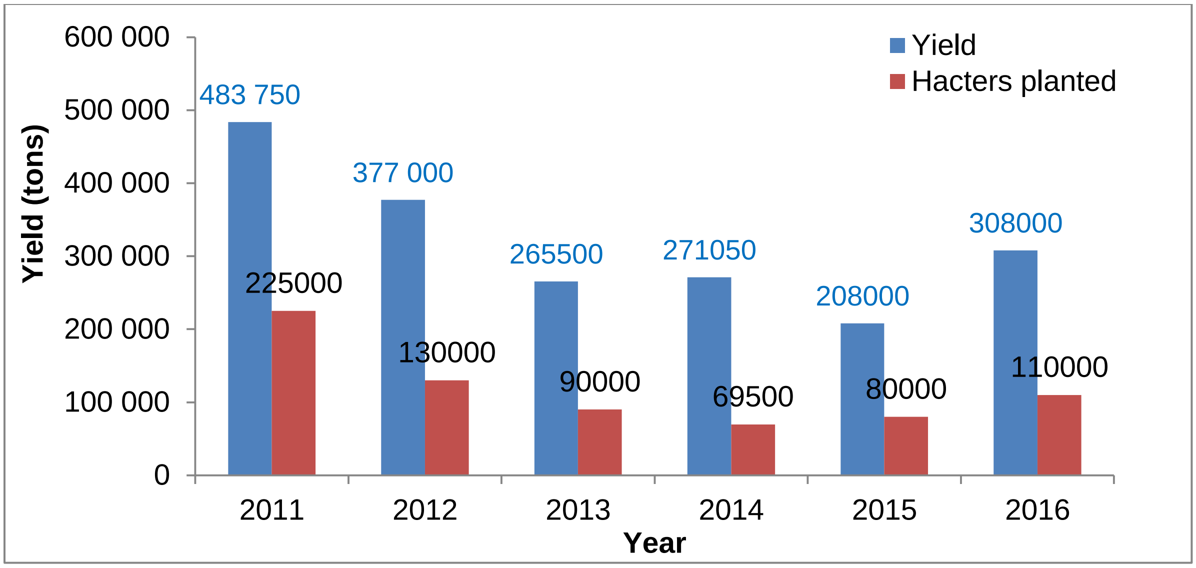

Figure 4.9 Estimated Free State wheat yield and hacters planted 2011-2016 (Source: CEC)

Figure 4.9 depicts the trend of estimated yield decreasing from the year 2011 to 2016 in the Free State province. This yield trend is in agreement with the farmer's observation of climate change, the decrease in rainfall and change in rainfall patterns as well as increases in temperature. In 2002 the Department of Agriculture (Department of Agriculture, 2002) wrote *"….should the trend hold South African domestic wheat consumption will outstrip domestic production by 2010''* Is this the situation to which they were referring to? Probably yes. Although the trend in Figure 4.9 agrees with the farmers' observations, there are interesting observations that are presented by the graph in this figure. First is that the decrease in estimated yield is complaint with the decrease in estimated hectares planted. Second is that the yield per unit area is not decreasing, except in 2015 and 2016. The main reason for these observations might be because of the fact that where this information was extracted (www.sagis.org.za/cec.html) it includes both irrigation and dryland wheat production (Crop Estimation Committee, 2017).

The third observation is that it is probable that farmers adopt the reduced hectares planted because they observe the climate change. This adaptation measure has come out sixth on the frequency scale in the survey results in Figure 4.3. A discrepancy is detected here because this survey indicated that farmers plant less hectares. Only 26%

of the surveyed farmers planted more than 200 hectares in the past five year (Figure 4.3). A finding which is in agreement with CEC estimation. However, in the farmers' measures of adaptation a reduction of hectares did feature among the most adopted mitigation measures. Reduction of planted hectares as mitigation came out stronger in later studies (Benhin, 2006).

CHAPTER 5

SUMARRY AND GENERAL RECOMMENDATIONS

5.1 Summary

This study had four objectives as stated in Chapter 1 and re-stated in Chapter4. This study has reviewed the Disaster Risk Management framework in South Africa and its prominent address to crop production and food security and the vulnerability to the impact of climate change. This study reviewed that South African Policy and legislative framework on Disaster Risk Management is well in existence and articulated to address the vulnerability of food security to climate change and any form of disaster. This is elaborated in section 4.2 of this study. South African national legislative framework and strategies for Disaster Risk Reduction Strategies appear to be in cohesion with the regional strategies.

This study has explored and determined that the Bethlehem commercial wheat farmers' perception of climate change on wheat production and the farmers' adaptation options are in place, 97.1% of the sampled farmers perceive that there has been some change in the climate over the years. There were 2.9% of the farmers who were not sure whether there was a change or not. This study has singled out climate factors that contribute to crop failures, wheat in particular, and food insecurity in South Africa as rainfall and temperature and their special boundaries. The farmers perceive climate change by observing that there are increases in temperature, no decreases, there are alterations in temperature ranges (average minimum and maximum temperature) and there is an alteration in temporal variations. On rainfall, the farmers' observation is that there are alterations in rainfall patterns, particularly a reduction in rainfall amounts.

On mitigation measures, the three most common internal farming adaptation measures indicated by sampled wheat farmers in Bethlehem are: changing planting time (23.6%), changing crop (22%), and changing cultivars (15.7%) in relative frequency of occurrence. Soil cultivation practices as an adaptation measure is not elaborated in this study due to the limited scope of the study, it is however one of the most important management practices in rain fed wheat production.

This study was able to assess the adaptation measures by farmers by using crop growth models (DSSAT). The simulation result indicated that changing cultivars, planting date and fertilizer level management can be one of the favorable adaptation measures to mitigate crop yield losses due to climate change. The model shows all three cultivars performing better on late planting dates than early planting dates. Elands performed higher than all the other cultivars under all fertilizer management levels. The highest grain yield was 3.4 t ha^{-1} for Elands. SST 124 and Betta DN were 1.5 and 1.4 tha^{-1} respectively under higher fertilizer management levels (75kg Nha^{-1}). Elands performed higher under low fertilizer management levels (25kg Nha^{-1}) with yields of 2.4 t ha^{-1} followed by 1.1 and 1.0 t ha^{-1} of SST 124 and Betta-DN respectively. Late planting combined with medium fertilizer levels (50kg Nha^{-1}) surpassed early planting combined with 75kg Nha^{-1} in yield by 32, 26 and 17% for Elands, SST 124 and Betta-DN respectively. Changing cultivars such as Elands combined with late planting dates and medium levels of fertilizer management suggest to be a solution to mitigate yield loss due to climate variability where yield of 2.5 t ha^{-1} is possible with a 70% probability chance.

An external mitigation measure considered by farmers is risk transfer mechanisms. Two risk transfer mechanisms considered in this study are state relief and crop insurance. On state relief, 77% of the sampled farmers' ratings are that state relief is not useful while only 23% rate state relief mechanisms useful. On crop insurance, 40% of the sampled farmers' ratings are that crop insurance is not useful and 60% rate crop insurance useful. The farmers' survey indicated 93.3% of the sampled farmers have access to weather information and warning systems while 6.7% do not have access. Sources of weather information most commonly accessed are the internet and television while the least accessed are science publications and extension services respectively.

Extension service is not a common source of weather information to the sampled commercial wheat farmers. Farming input retailers and other private companies have extension serves, and there is state extension services in the Department of Agriculture. It was not distinguished in this study survey on which extension service farmers were questioned. The last objective of this study was to advise the agricultural support system on strategic areas for intervention in order to mitigate the impact of climate change on wheat production. A schematic representation for preliminary recommndations was designed as a Decision Support Tool (DST) both the disaster risk management and database structure were implemnted (Figure 4.8). The study has finally drawn preliminary and general recommendations for various strategic levels of support systems being, Policy making, Research, and Business sector.

5.2 General Recommendations

The last objective of this study was to advise the agricultural support system on strategic areas for intervention in order to mitigate the impact of climate change on wheat production. In conclusion, this study would like to draw attention of the following strategic levels of support systems, Policy making, Research, and Business sector, the recommendations are as follows:

- State relief as mitigation to food insecurity due to climate change can assist to keep crop farmer in the business of farming and that will ensure long-term food security to the nation. An in-depth research is recommended to ascertain the commercial farmers rating of State relief programs and the efficiency of implementation of existing policies and institutional arrangements.
- This study assumes that, if the crop models have indicated a positive impact of the adaptation measure (changing planting date, changing cultivar and fertilizer levels) and the farmers too has identified them as mitigation measures in their practices, their wide adaption may be one of the strategies towards mitigating the risk of crop losses and thus improving food security. Such measures should be supported in terms of research resources and training.
- Changing crops due to climate change, if adopted widely, may pose a threat to food security as farmers may choose to plant high value crops instead of staple

food crops. More and more strategic mitigation measures to lessen the impact of climate change should be sought to support continuous production of staple food crops. That may require strong public and business sector collaboration.

- It is evident from the survey that fertilizers were not indicated as the preferred adaptation measure by many farmers. Yet it is well documented how judicious use of fertilizers can increase crop yields under certain stressful environmental conditions. This practice is probably considered an unviable option because of the high costs related to fertilizers in crop production. Assistance in financing the use of fertilizers may help farmers to consider judicial use of fertilizers as a mitigation to lessen the impact of climate change.

REFERENCES

Abayisenga, O., 2015. *Impacts of Climate Change on Durum Wheat (Triticum turgidum L. var durum) Production: Analysis of Adaptation Measures in the Central Rift Valley of Ethiopia,* Haramaya University: M.SC Thesis.

Abid, M., Scheffran, J., Schneider, U. A. & Ashfaq, M., 2015. Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province, Pakistan. *Earth Syst. Dynam,* Volume 6, pp. 225-243.

Abraha, M. G. & Savage, M. J., 2006. Potential impacts of climate change on the grain yield of maize for the midlands of KwaZulu-Natal, South Africa.. *Ecosystems and Environment,* Issue 115, pp. 150-160.

Adams, R. M., Hurd, B. H., Lenhart, S. & Leary, N., 1998. Effects of global climate change on agriculture: an interpretative review. *Climate Research,* Volume 11, pp. 19 - 30.

Amadou, M. L., Villamor, G. B., Attua, E. M. & Traoré, S. B., 2015. Comparing farmers' perception of climate change and variability with historical climate data in the Upper East Region of Ghana. *Ghana Journal of Geography,* 7(1), pp. 47-74.

Apata, T. G., 2011. Factors influencing the perception and choice of adaptation measures to climate change among farmers in Nigeria. Evidence from farm households in Southwest Nigeria. *Environmental Economics,* 2(4).

ARC-SGI, 2009. *Wheat Production Guidelines for Small-Scale Farmers.* Bethlehem: Agricultural Research Council - Small Grain Institute.

ARC-SGI, 2013. *Wheat Production Guideline. Summer rainfall regions.* Bethlehem: Agricultural Research Council – Small Grain Institute.

Asseng, S. et al., 2015. Rising temperature reduce global wheat production. *Nature climate change*, 15 February, pp. 143-147.

Attri, S. D. & Rathore, L. S., 2003. Simulation Impact of Projected Climate Change on Wheat in India. *Int. J. Climatol,* Volume 23, pp. 693-705.

Baas, S., Ramasamy, S., Dey de Pryck, J. & Battista, F., 2008. *Disaster risk management systems analysis A guide book.* Rome: FAO.

Basso, B., Cammarano, D. & Carfagna, E., 2013. *Review of Crop Yield Forecasting Methods and Early Warning Systems.* [Online]
Available at:

http://www.fao.org/fileadmin/templates/ess/documents/meetings_and_workshops/GS_SAC_2013
[Accessed 23 January 2015].

Beletse, J. G. et al., 2014. Projected Impacts of Climate change Scenarios on the Production of Maize in Southern Africa: An Intergrated Assessment Case Study of the Bethlehem District, Central Free State, South Africa. *Handbook of Climate change and Agroecosystems,* 13(24), pp. 119-150.

Benhin, J. K. A., 2006. *Climate Change and South African Agriculture: Impact and adaptation options.,* Pretoria: CEEPA.

BFAP, 2016. *Baseline Agricultural Outlook 2016-2025. Puting Plans into Action: Agriculture and Economic growth in South Africa,* s.l.: BFAP.

Blignaut, J., Uckermann, L. & Aronson, J., 2009. Agriculture production's sensitivity to climate change in south Africa. *south African Journal of Science,* Volume 105, pp. 61-68.

Bryan, E., Deressa, T. T., Gbetibouo, G. & Ringler, C., 2009. Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science & Policy,* Volume 12, pp. 413-426.

Cattaneo, A. et al., 2012. *Developing a Climate - Smart Agriculture Strategy at the Country Level: Lessons from recent experience.* Rome, Italy: FAO.

Chuku, C. A. & Okoye, C., 2009. Increasing resilience and reducing vulnerability in Sub-Saharan African agriculture: Strategies for risk coping and management. *African Journal of Agricultural Research,* Vol. 4(13), pp. 1524-1535.

City Population, 2017. *City Population.* [Online]
Available at: https://www.citypopulation.de/php/southafrica-freestate.php?cityid=470001001
[Accessed 07 04 2017].

Cooper, P. J. M., Stern, R. D., Noguer, M. & Gathenya, J. M., 2015. Climate change adaptation strategies in Sub-Saharan Africa: foundations for the future. In: B. R. Singh, ed. *Realities, Impacts Over Ice Cap, Sea Level and Risks.* Reading : InTech Open , pp. 327-356.

Crop Estimation Committee, 2017. *www.sagis.org.za.* [Online]
Available at: www.sagis.org.za/cec.html
[Accessed 03 02 2017].

DAFF, 2002(a). *Disaster Response and Management Particularly with regard to Veld fires, Drought, Floods and Migratory Pests control around the Country: Presentation to the portfolio committee on Agriculture, Forestry and Fisheries.* Pretoria: DAFF 30 October 2002.

DAFF, 2002(b). *The Integrated Food Security Stragey for South Africa,* Pretoria: s.n.

DAFF, 2005. *Drought Management Plan (DMP). A Discussion Document for Public Comment,* s.l.: s.n.

De Jager, J. M., Potgieter, A. B. & Van Den Berg, W. J., 1998. Framework for Forecasting the Extent and Severity of Drought in Maize in the Free State Province of South Africa. *Agricultural Systems,* 57(3), pp. 351-365.

Department of Agriculture, 2002. *The Integrated Food Security Stratergy for South Africa,* Pretoria: Republic of South Africa.

DFID Department of International Development, n.d. *Reducing the Risk of Disasters- Helping to Achieve Sustainable Povery reduction in a Vulnerable Wold: A DFID policy paper.* London: Stairway Communications.

Disaster Managment Act, 2008. *Disaster Management Act 57 of 2002.* s.l.:Republic of South Africa.

Du Pisani, L. G., Fouche, H. J. & Venter, J. C., 1998. Assessing Rangeland Drought in South Africa. *Agricultural Systems,* 57(3), pp. 367-380.

Ewert, F. et al., 2014. Crop modelling for integrated assessment of risk to food production from climate change. *Environmental Modelling and Software,* Volume xxx(2014), pp. 1-17.

FAO, n.d. *Disaster Risk Management in food and agriculture: Rome Partnership for Disaster Risk Management,* Rome: FAO.

Fauchereau, N., Trzaska, S., Rouaul, M. & Richard, Y., 2003. Rainfall Variability and Changes in Southern Africa during the 20th Century in the Global Warming Context. *Natural Hazards,* Volume 29, pp. 193-154.

Free State Provincial Government, 2010. *Free State Provincial Government Incoprating Private Sector: Sustaining Economic Growth Through Service Delivery,* Bloemfontein: Free Stste Government.

Gadédjisso-Tossou, A., 2015. Understanding Farmers' Perceptions of and Adaptations to Climate Change and Variability: The Case of the Maritime, Plateau and Savannah Regions of Togo. *Agricultural Sciences,* Volume 6, pp. 1441-1454.

Hageback, J. et al., 2005. Climate variability and land use change in Danagou, watershed, China—Examples of small scale farmers' adaptation. *Climatic Change,* Volume 72, p. 189–212.

Haverkort, A. J., Franke, A. C., Engelbrecht, F. A. & Steyn, J. M., 2013. Climate Change and Potato Production in Contrasting South African Agro-ecosystems 1. Effects on Land and Water Use Efficiency. *Potato Research,* Volume 56, pp. 31-50.

Haverkort, A. J. & Hillier, J. G., 2011. Cool Farm Tool - Potato: Model Description and Performance of Four Production Systems. *Potato Reserch,* Volume 54, pp. 355-369.

HLPE, 2012. *Food security and climate change. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security,* Rome: FAO.

Hoogenboom, G. et al. eds., 2010. Decision Support System for Agrotechnology Transfer Version 4.5. Volume 1. In: s.l.:s.n.

Howden, S. M. et al., 2007. Adapting agriculture to climate change. *PNAS,* 104(50), pp. 19691-19696.

IPCC, 2007. Climate Change 2007. In: R. K. Pachauri & A. Reisinger, eds. *Synhesis Reoprt. Contribution of Working Groups I, II and III to the Fouth Assessment Reoprt of the Intergovernmental Panel on Climate Change.* s.l.:IPCC, Geneva, Switzerland, p. 104.

IPPC, 2000. *International Panel on Climate Change Summary for Policy Makers: Emissions Scenarios,* s.l.: IPPC.

ISDR, 2008. *CLimate Change and Disaster Risk Reduction, Brief Note 01.* Geneva: United Nation.

Jones, J. W. et al., 2003. The DSSAT cropping system model. *Europ. J. Agronomy,* 18(235), pp. 235-265.

Jones, J. W. et al., 2003. The DSSAT cropping system model. *Europ. J. Agronomy,* 18(2003), pp. 235-265.

Jury, M. R., 2013. Climate trends in southern Africa. *South African Journal of Science,* Volume 109(Number 1/2).

Kerr, N. J., Siddique, K. H. M. & Delane, R. J., 1992. Early sowing with wheat cultivars of suitable maturity increses grain yield of spring wheat in a short season environment. *Australian Journal of Experimental Agriculture,* Volume 32, pp. 717-33.

Kpongor, D. S., 2007. Spatially explicit modeling of sorghum (sorghum bicolor (L.) Moench) production on complex terrain of a semi-arid region in China using APSIM. *Inagural Dissertation. Dr. agr. Rheinischen Friedrich-Wilelmas-Universitat.*

Kruger, A. C. & Shongwe, S., 2004. Temperature Trends in South Africa: 1960–2003. *Int. J. Climatol,* Volume 24, pp. 1929-1945.

Leedy, P. D. & Ormrod, J. E., 2005. *Practical Research Planing and Design.* 8th ed. Prentice Hall: Prentice Hall.

Lindeque, R. C., 2008. *The influence of environment on the expression of Russian Wheat Aphid, Diuraphis noxia (Kurdjimov) resistance.* Bloemfontein, South Africa: MSc.Thesis.

Lourens, U. W. & De Jager, J. M., 1997. A computerized Crop-specific Drought Monitoring System: Design Concepts and Initial Testing. *Agricultural Systems,* Volume 53(1997), pp. 303-315.

LTAS, n.d. *Climate Change Adaptation: Perspectives of Food Security in South Africa. towards an integrated Economic Analysis,* s.l.: Long Term Adaptation Scenarios Flagship Research Programm.

LTAS, n.d. *Climate Change Adaptation: Perspectives for Disaster Risk Reduction and Management in South Africa Provisional modelling of drought, flood and sea level rise impact and a description of adaptation responses,* s.l.: Long Term Adaptation Scinarios Research Flagship Program.

LTAS, n.d. *Climate Change Adaptation: Perspectives of Disaster Risk Reduction and Management in South Africa,* s.l.: s.n.

Maddison, D., 2006. The perception of and adaptation to climate change in Africa. *Centre for Environmental Economics and Policy in Africa, University of Pretoria, South Africa,* CEEPA Discussion Paper(No. 10).

Ma, L. et al., 2011. Protocol for Parameterization and Calibration of RZWQM2 in Field Research. In: L. Ahuja & L. Ma, eds. *Methods of introducing system models into agricultural research.* ASA, CSSA, SSSA, 5585 Guilford Rd., Madison, WI 53711-5801, USA. : Advances in Agricultural Systems Modeling Series 2.

Meagher, B. O., Du Pisani, L. G. & White, D. H., 1998. Evolution of Drought Policy and Related Science in Australia and South Africa. *Agricultural Systems,* 57(3), pp. 231-258.

Mohammed, H. I., Abdel, R. M., Seed, A. & Omran, M. A., 2010. Utilization of water budget model for early season forecasting of Sorghum yield and optimum sowing date in Gadaref mechanized rain fed areas Sudan. *Agric. Biol. J. N. Am,* 1(4), pp. 510-525.

Msongaleli, B., Rwehumbiza, F., Tumbo, S. D. & Kihupi, N., 2014. Sorghum Yield Response to Changing Climate conditions in Semi-Arid Central Tanzania: Evaluating Crop Simulation Model Applicability. *Agric. Sci.,* Volume 5, pp. 822-833.

Muchow, R. C., Hammer, G. L. & Vanderlip, R. L., 1994. Assessing climate risk to sorghum production in water-limited sub-tropical environments II. Effects of planting date, soil water at planting, and cultivar phenology. *Field Crops Research,* 36(3), pp. 235-236.

National Disaster Management Framework, 2007. *National Disaster Management Framework of 2005.* s.l.:Republic of South Africa.

National Water Act, 1998. *National Water Act No. 36 of 1998.* Cape Town: Republic of South Africa.

Nelson, G. N. et al., 2009. *Climate Change: Impact on Agriculture and costs of Adaptation. Food Policy Report..* Washinton DC, USA: IFPRI.

NEPAD, 2004. *Towards Sustainable Development in Africa. Report on the Status of Disaster Risk Management and Disaster Risk Assessment in Africa,* s.l.: s.n.

Nkulumo, Z., Crespo, O. & Hachigonta, S., 2013. Crop response to climate change in Southern Africa: A comprehensive review. *Global and Planetary Change, Elsevier,* Issue 111, pp. 118-126.

Ouabbou, H. & Paulsen, G. M., 2000. Evaluation of selection criteria for performance of wheat cultivars during high temperature stress in the field. In: C. Royo, D. F. N. Nachit M & J. Araus, eds. *Durum wheat improvement in the Mediterranean region: New challenges. Zaragoza:.* s.l.:CIHEAM, pp. 303-307.

Paolo, R., Joachim, K., Benno, K. & Christian, K., 2015. Impact of climate change on the phenological development of winter wheat, sugar beet and winter oilseed rape in Lower Saxony, Germany. *Journal of Plant Diseases and Protection,* 1(122), pp. 16-27.

Pasi, J. M., 2014. *Modeling the Impact of Increased Air Temperature On Maize Yields in Selected Areas of the South African Highveld Using the Cropsyst Model.* Pietermaritzburg, South Africa: MSc. Thesis.

Procter, M., 2017. *Disaster Management and State relief, DAFF, Bloemfontein* [Interview] (13 May 2017).

Ramirez-Villegas, J., Jarvis, A. & Läderach, P., n.d. *http://ciat-library.ciat.cgiar.org.* [Online]
Available at: http://ciat-library.ciat.cgiar.org/Articulos_Ciat/2011%20Approved-Empirical-approaches-assessing-impacts-EcoCrop-v9-nochanges.pdf
[Accessed 26 04 2017].

Reed, S. B., 1992. *Introduction to Hazards.* 1st ed. s.l.:UNDP Disaster Management Training Programme.

Rezzoug, W., Gabrielle, B., Suleiman, A. & Benabdeli, K., 2008. Application and evaluation of the DSSAT - wheat in the Tiaret region of Algeria. *African Journal of Agricultural Research,* 3(4), pp. 284-296.

Robock, A. et al., 1993. Use of General Circulation Model output in the Creation of Climate Change Scenarios for Impact Analysis. *Climatic Change,* Volume 23, pp. 293-335.

Rosegrant, M. et al., 2013. *Food Security in a World of Growing Natural Resource Scarcity: The role of Agricultural Technologies.* Washington DC, USA: IFPRI.

Saseendran, S. A. et al., 2005. Simulating Planting Date Effects on Corn Production Using RZWQM and CERES-MAIZE Models. *Agron. J,* Volume 97, pp. 58-71.

Saseendran, S. A. et al., 2004. Modeling Nitrogen Management Effects on Winter Wheat Production Using RZWQM and CERES-Wheat. *Agron. J,* Volume 96, pp. 615-630.

Saulter, C., 2013. *Texas University.* [Online]
Available at: https//sites.utexas.edu/mecc/2013/11/17/climate-smart-agriculture-more-rice-less-methane/
[Accessed 26 03 2017].

Singels, A., 2015. *Crop modeling* [Interview] 2015.

Singels, A. et al., 2008. Modelling crop growth and water relations in South Africa: Past achievements and lessons for the future. *S. Afr. J. Plant & Soil,* 27(1), pp. 46-65.

South African Weather Service Amendment Act, 2013. *South Africa Waether Service Amendment Act No. 48.* Cape town: Government Gazette, Republic of South Africa.

Stephens, D. J. & Lyons, T. J., 1998. Variability and trends in sowing dates across the Australian wheatbelt. *Aust. J. Agric. Res,* Volume 49, pp. 1111-18.

Stockle, C. O., Kjelgaard, J. & Bellochi, G., 2004. Evaluation of established weather data for calculating Penman-Montheith reference crop evaluation. *Irrig. Sci.,* Volume 23, pp. 39-46.

Thompson, D. & Powell, R., 1998. Exceptional Circumstances Provisions in Australia - is There too Much Emphasis on Drought?. *Agricultural Systems,* 57(3), pp. 469-488.

Trochim, W. M. K., 2006. *Research Methods Knowledge Base.* [Online]
Available at: http://www.socialresearchmethods.net/kb/index.php
[Accessed 16 October 2016].

Tubiello, F. N., Donatelli, M., Rosenzweig, C. & Claudio, O. S., 2000. Effect od climate change and elevated CO2 on cropping systems: model predictions at two Italian locations. *European Journal of Agronomy,* Volume 13, pp. 179-189.

UK, 2017. *UK Climate Projections.* [Online]
Available at: http://ukclimateprojections.metoffice.gov.uk/22620
[Accessed 31 May 2017].

UN/ISDR, 2002. *Living with Risk. A global review of disaster reduction initiatives.* Geneva: ISDR.

UNICEF, 2011. *Exploring the Impact of Climate Change on Children in South Africa,* Pretoria: UNICEF, South Africa.

United Nations Corporate Strategy for Disaster Reduction, n.d. *Disaster Reduction and Sustainable Development: Understanding the links between vulnerability and risk to disasters related to development and environment.* Geneva: UN/ISDIR.

USDA, 2016. *Republic of South Africa. Grain and Feed Annual. Report on the supply and demand for grains and feed in South Africa,* s.l.: USDA Foreign Agricultural Services. Global Agricultural Information Networks.

USDA, 2017. *Republic of south Africa. Grain and Feed Annual. Report on the supply and demand for grains and feed in South Africa,* s.l.: USDA Foreign Agricultural Services. Global Agricultural Information Networks.

Van Zyl, K., 2006. *A study on a Disaster Risk Management Plan for the South African Agricultural Sector,* Pretoria: s.n.

Vedwan, N. & Rhoades, R., 2001. Climate change in the Western Himalayas of India: a study of local perception and response Climate Research. 19: 109–117.. *Climate Research,* Volume 19, p. 109–117.

Waha, K. et al., 2012. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change.*

Walker, N. J. & Schulze, R. E., 2008. Climate change impacts on agro-ecosystem sustainability across three climate regions in the maize belt of South Africa. *Agriculture, Ecosystem and Environment,* Volume 124, pp. 114-124.

Wandrag, E., 2017. *Crop Insurance and Climate Change, Agri Seker, Bethelehem* [Interview] (10 May 2017).

White, J. & Edwards, J., 2008. *Wheat Growth and Development.* s.l.:NSW Department of Primary Industries.

Wilhite, D. & Glantz, M., 1985. Understanding the Drought Phenomenon: The Role of Definitions. *Water International,* 10(3), pp. 111-120.

World Conference on Disaster Reduction, 2005. *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters,* s.l.: ISDR.

APPENDICES

APPENDIX I

Questionnaire to Wheat production farmers: on agro-climate, early warning, and adaptation to climate change

N.B All information will be treated confidential.

Farmer information

Name: ………………………………………… Contact ……………………………….

Region:………………………….. Area:…………………

Farming practices

1. What is your 5 year average wheat area planted (ha):…………
2. Which cultivars do you plant most

Cultivar	Planting time	Harvesting time	

3. What is your 5 year average yield (ton/ha):………………………..

Farmer perceptions on climate change

1. How many years of farming experience do you have?

<10	10 - 20	20 - 30	30 - 40	>40

2. Did you feel/recognise any change in weather in the past 10 years?

Yes	No

3. If Yes what is the change in the following two factors?

Temperature

	Increased
	Decreased
	Altered the range
	Altered time (temporal)
	No change
	Don’t know
	Other

Rainfall

	Increased
	Decreased
	Altered the range
	Altered time (temporal)
	No change

	Don't know
	Other

4. The following anomalies related to climate change do occur. How frequent did they occur in 10 years?

Anomalies	**Frequency in 10 years(number)**	**Can't recall (X)**
Increased number of seasons without enough rainfall		
Rainfall starts late		
Rainfall starts early		
Inconsistent rainfall during the season		
Floods		
Drought		
Extreme cold winter		
Extreme hot summer		

5. Adaptation strategies for wheat production. What crop production adaptations do you consider when these anomalies occur?

Anomalies	Change crop variety	Change soil cultivation practices	Add more fertiliser	Reduce fertiliser	Change crop	Change plating date	Change amount of crop land	No adaptation	Other
Seasons without enough rainfall									
Rainfall starts late									
Rainfall starts early									
Inconsistent rainfall during the season									
Drought									
Extreme cold winter									
Extreme hot summer									

6. Climate information and access. Do you have access to early warning systems about climate?

Yes	No

7. If Yes what type of warning?

Type of warning e.g hail etc	**Warning system:** 1= Radio, 2=TV, 3=Extension services, 4=Landbouweekblad, 5=Science publications, 6=Internet

8. How would you rate the weather warning information that you receive?
   1=Poor, 2=Average, 3=Good

Timeliness	
Adequacy	
Frequency of dissemination	
Usefulness	
Delivery	

9. Crop insurance and State relief.
   Is Insurance helpful as mitigation for crop losses? Please rate on a scale of 1 - 5

1. not	2. less	3. highly	4. very	5. extremely

Is State relief helpful as mitigation for crop losses? Please rate on a scale of 1 - 5

1. not	2. less	3. highly	4. very	5. extremely

End of questionnaire
And thank you for your time.

APPENDIX II

STAKEHOLDER INTERVIEWS

INVESTIGATING CLIMATE CHANGE EFFECTS ON WHEAT YIELDS AND EXTERNAL COPING MECHANISMS

This is an academic study and we assure you that your responses will be treated with confidentiality and will be used strictly for learning purposes and determine possible climate change mitigation strategies. .

SECTION A

1. Name of respondent (optional) ……………………………………………………………………

2. Institution represented …………………………………………………………

3. What service(s) are provided by the institution?

………
………
………
………………………………………………………………………………

4. For how long has the institution been in service? …………………………………

5. What is the role of the organization during disaster periods?

………
………
………
………………………………………………………………………………

SECTION B

***(please answer the relevant question pertaining to the institution*)**

6. Explain how climate change affect your services (e.g. reducing or adding other aspects to your services).

7. Record all the procedures followed when rendering services (any kind of service to farmers).

8. Record all the coping mechanisms supported by institution during droughts or other disasters.

APPENDIX III

Soil physical and hydrological properties fitted to calibrate the DSSAT model

Description	**Variable**	**Value**		
Soil identification	SOIL ID	Avalon		
Soil Albedo fraction	SALB	0.13		
Drainage coefficient (fraction/day)	SLDR	0.5		
SCS Runoff coefficient	SLRO	70.1		
Soil Nitrogen factor	SLNF	1.0		
Soil Phosphorus factor	SLPF	1.0		
		Soil depth (cm)		
Soil Layer Base (soil depth)	SLLB (cm)	20	50	90
Soil Lower Limit	SLLL (mm^3/mm^3)	0.0894	0.1164	0.1325
Soil Drained upper limit	SLDUL (mm^3/mm^3)	0.1871	0.22976	0.24801
Soil Saturation	SLSAT (mm^3/mm^3)	0.401592	0.447254	0.463246
Soil Bulk density	SLBDM (g/cm^3)	1.064219	1.185224	1.227601
Soil Organic Carbon	SLOC (g C/100g)	0.65	0.6	0.6
Soil Clay content	CLAY (%)	10	25	25