The Economic Impact of Climate Change on Maize Production in the Free State Province, South Africa

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Abstract

Higher concentrations of CO_2 in the atmosphere is a major influence on climate change globally. Climate change is caused by greenhouse gases trapping too much heat from the sun in the atmosphere and thus, altering the climate through a rise in global surface temperatures and changing precipitation patterns. CO_2 is the most prominent greenhouse gas found in the atmosphere and it is reported that by the turn of the century the CO_2 concentration levels will have doubled if the current rate of emissions continues.

However, the increase in atmospheric levels of the gas has been found to increase the capacity of maize plants and their water use efficiency to achieve higher yields through CO_2 fertilisation. Simulation experiments conducted by the Rhodes University Botany Department found that the effect of elevated levels of CO_2 of double the current concentration offsets the negative effects of drought on maize.

A case study was conducted on commercial maize farmers in two regions of the Free State province in South Africa to estimate the economic impact of climate change on maize production. Although production is increasing in the province, adaptation to the changing climate is key to the sustainability of production. There is a trade-off between the negative effects of higher CO_2 levels changing the climate and the positive effect of CO_2 fertilisation. As predicted, the economic impact of climate change is the disruption of farming practices and the increase in costs of production as a result of adapting to climate change. Using a gross margin analysis, the study found that the larger maize farmers who benefit from economies of scale are able to adapt and grow their production whilst the smaller farmers are being pushed out of the market.

Declaration

This thesis has not been submitted to a university other than Rhodes University, Grahamstown, South Africa. The work presented here is that of the author, unless stated otherwise.

………………………………………… 3 November 2020

Richard Johnson Date

Table of Contents

Abstract i

Declaration ii

Table of Contents iii

Acknowledgements vi

List of Figures vii

List of Tables vii

CHAPTER ONE: Estimating the Impacts of Climate Change 1

1.0 Introduction 1

1.1 Definition and Evidence of Climate Change 1

1.2 South African agricultural sector 3

1.3 Maize production in South Africa 3

1.4 Problem Statement 4

1.5 Aims and Objectives 5

1.5.1 Aim 5

1.5.2 Objectives 5

1.6 Method 5

1.7 Structure 7

CHAPTER TWO: Climate Change: Causes, Effects and Economic Impacts 8

2.0 Introduction 8

2.1 Climate Change 9

2.2 Downscaling Climate Models 9

2.3 Elevated CO_2 10

2.3.1 CO_2 Fertilisation 11

2.3.2 Temperature 12

2.3.3 Drought 15

2.3.4 Combined effect of temperature and drought 16

2.4 Effects of elevated CO_2 on maize production 17

2.5 Grain Quality 19

2.6 Adaptations to Climate Change 20

2.7 Mitigation 22

2.8 Economic Impact 23

2.9 Conclusion 25

CHAPTER THREE: Research Approach: Paradigm, Methodology and Methods 26
3.0 Introduction 26
3.1 Aim of the study 26
3.2 Study Design 27
3.3 Primary data collection 28
3.3.1 Simulating experiments 28
3.3.2 Farmer questionnaire 28
3.4 Secondary data collection 29
3.5 Questionnaire design 29
3.6 Sample and representation 30
3.7 Ethical Considerations 30
3.8 Methods and Methodology 31
3.9 Gross Margin Analysis 33
CHAPTER FOUR: Background and Context 36
4.0 Introduction 36
4.1 Climatic Requirements 36
4.1.1 Temperature 36
4.1.2 Moisture 37
4.2 Maize Production in South Africa 37
4.2.1 Free State Province 39
4.2.2 Mpumalanga 40
4.2.3 North West 40
4.3 Established Practices 41
4.3.1 Tillage 41
4.3.1.1 Zero till 41
4.3.1.2 Mulching 42
4.3.1.3 Reduced tillage 42
4.3.1.4 Conventional tillage 43
4.3.2 Planting Dates 43
4.3.3 Plant populations 44
4.4 Previous Studies 44
4.5 Rhodes University CO_2 Fertilisation Experiments 46
4.6 Potential economic impact of eCO_2 on maize production 49
4.7 Conclusion 53
CHAPTER FIVE: Analysis of Survey 55
5.0 Introduction 55

5.1 Study Site 55
5.1.1 Climate 56
5.1.1.1 Temperature 56
5.1.1.2 Precipitation 59
5.2 Questionnaire response 61
5.3 Maize varieties 64
5.4 Portion of income from maize 65
5.5 Other crop cultivation and livestock 67
5.6 Output 68
5.7 Costs of Production 69
5.8 Adaptations 70
5.9 Gross Margin Analysis 73
5.10 Conclusion 76
CHAPTER SIX: Discussion, Conclusion and Recommendations 78
6.0 Introduction 78
6.1 Discussion 78
6.2 Summary 80
6.3 Limitations, Assumptions and Shortfalls 82
6.4 Conclusion and recommendations 83
Bibliography 84
Appendix 96

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List of Figures

Figure 5.1: Koppen Climate Classification of the Free State Province, South Africa 57
Figure 5.2: Average temperature of Viljoenskroon 58
Figure 5.3: Average temperatures of Ladybrand 59
Figure 5.4: Average rainfall of Viljoenskroon... 60
Figure 5.5: Average rainfall of Ladybrand 60
Figure 5.6: Eastern production region 61
Figure 5.7: Western production region... 62
Figure 5.8: Portion of maize income to total annual income 66
Figure 5.9: Supplementary crops cultivated 68
Figure 5.10: Adaptation methods used by farmers. 72

List of Tables

Table 4.1: Percentage contribution of total maize production by each province 38
Table 4.2: Contribution of each province to the total production of maize in South Africa................. 39
Table 4.3: Rainfall data of Ladybrand 2010 – 2019... 51
Table 4.4: Rainfall data of Viljoenskroon 2010 – 2019 51
Table 5.1: Crops grown and their seasons in the Free State province... 56
Table 5.2: Questionnaire response for the West 62
Table 5.3: Questionnaire response for the East.. 63
Table 5.4: Total gross margin for maize production and market efficiency 74
Table 5.5: Gross margin per hectare... 75

CHAPTER ONE

Estimating the Impacts of Climate Change

1.0 Introduction

Considering that climate change is an inescapable reality, the question regarding the quantifiable economic effect that these changing climatic conditions will have on the level of agricultural production arises. Plenty of literature exists on the effect that elevated carbon dioxide (CO_2) has on the plants but there seems to be a lack of information on what the economic impact is. In particular, what the changing climatic conditions are costing commercial maize farmers and how it is affecting the maize farming industry.

The economic discussion on the effect of climate change on maize production is made through the contrast between the positive and negative effects of elevated levels of CO_2 in the atmosphere. According to Schulze (2016), the effect should be seen in terms of the change of productivity in farming operations as well as the risk of farming operations being disrupted. Firstly, the change of productivity is explored using crop simulations and identifying whether there is an increase or decrease of crop production under different climatic conditions. Secondly, the disruption of farming operations is reviewed by the extent of the changes in farming practices needed to adjust to the changing climate.

The research project attempted to estimate the economic impact of climate change on maize production in the Free State province of South Africa. The project focused on climate change as a direct result of increasing levels of CO_2 in the atmosphere. The project will focus on the production of maize with reference, in the literature review, on other crops to gain an insight on the effect that a changing climate has on grain crops. Through this process one can estimate the future impact on crop yields and the economic costs to farmers was estimated.

1.1 Definition and Evidence of Climate Change

Climate change can be defined as the observed change in weather data over an extended period of time (Dore, 2005), manifested as changes to precipitation patterns, regional temperatures, humidity and wind. Such changes impact crops because of their requirements for large quantities of water and because climatic factors effect rates of plant metabolism and drive water loss. However, climate change is also associated with changing atmospheric CO_2 concentrations, which has direct effects on the process of photosynthesis and effects on water loss as plants stomata respond to the level of CO_2 in the atmosphere (Lawlor, 1995; Lawlor, 2002; Leakey et al, 2004). Climate change is caused by greenhouse gases increasing the amount of heat trapped from the sun in the atmosphere. This is commonly known as the greenhouse effect (El Zein and Chehayeb, 2015). According to the fifth assessment report of the Intergovernmental Panel for Climate Change (IPCC) (2013), the increased concentrations of greenhouse gases from human emissions are the predominant cause of the warming of the earth's climate. Whilst there are a number of greenhouse gases which occur naturally in the atmosphere, elevated levels of CO_2 in the atmosphere through excessive emissions is one of the major global causes of climate change (DEA, 2011).

The warming has caused an increase in the frequency and intensity of weather events as well as greater climate variability. The IPCC (2013) report argues that this is evidenced by the increase in global temperatures, with the last decade being the hottest decade on record, the rise in sea level as well as the change in the average rainfall patterns, with some areas receiving more rainfall (Northern Europe) and some less (Southern Africa).

Evidence of this rise in the average temperature appears when looking at South Africa. In a study of 26 climatic stations in the country, 24 have had a positive trend in the annual average temperature with 18 of the 24 being significant (Kruger and Shongwe, 2004). A study conducted by the Department of Environmental Affairs found that in South Africa, the average temperature is expected to rise by 1 ^{o}C in coastal areas and by 3 ^{o}C in the interior by 2050. By the end of the century these increases will be 3 ^{o}C and 5 ^{o}C respectively.

Similarly, changes in South Africa's average rainfall patterns have also been predicted. Studies conducted by the DEA (2011); Engelbrecht et al. (2009); Engelbrecht et al. (2011); Engelbrecht et al. (2012); Hewitson and Crane (2006) and Tadross et al. (2011) conclude that South Africa is expected to become drier in general with some changes in the timing of the rainfall seasons. It is also predicted that there will be changes in extreme rainfall events such as the duration of dry spells, heat waves and heavy rainfall.

Lobell et al. (2011) conducted a study on the effect that these changes had on maize in Africa. The results showed that for every day spent above 30 ^{o}C, the final yield of maize reduced by 1% under good rain conditions and by 1.7% under drought conditions. Approximately 65% of the African continent would be affected by optimal rain conditions and 100% of the continent is affected by drought conditions (Lobell et al., 2011).

Climate change is a reality that scientific evidence has proven to be a long-term threat, not only to the agricultural sector, but the global economy and well-being. According to Stern (2007), the cost of climate change, overall, would be the equivalent of at least 5% of the global economy every year with the potential of the cost increasing up to 20% if no changes are made to the current practices. However, Stern (2007) believes that climate change is the greatest and widest ranging market failure that has ever been reviewed and as a result, a unique challenge is presented to the world of economics. The economics of the risk and uncertainty of climate change must, therefore, also be highlighted and considered. Although it is impossible to predict the consequences of climate change with complete accuracy, enough is known to understand the risks associated with it. As a result of Stern (2007), the economics of risk and uncertainty are included in the research project as the costs incurred in adapting to, or mitigating these risks and should be seen as an investment. Therefore, risk and uncertainty are considered when determining the economics of climate change

1.2 South African agricultural sector

It is estimated that the South African Agricultural Sector contributed 2,59% of GDP in 2018 (SA Market Insights, 2019). This appears too small of a contribution for a sector that comprises of over 80% of the available land in the country and using more than 60% of the country's water (Greyling, 2015). However, it is not unusual. In the US, the agricultural sector only contributes 1% to their GDP and although the contribution of the sector to GDP may be small, the sector's true contribution is greater (Greyling, 2015). The agricultural sector contributes through the supply of food, agricultural trade, the linkage it provides between sectors and as an employment source. The primary agricultural sector is important to South Africa having an annual growth of 7,5% since 1994 according to the Economic Review of South African Agriculture (2018).

According to South Africa's Second Annual Climate Change Report (SASACCR) (DEA, 2018), the agricultural sector is under exceptional threat of climate change. The threats associated with water are the most dangerous (Kreft et al., 2017). Increases in the variability of the climate and a rise in extreme weather patterns such as drought and floods impact the quality of our water as well as it's availability. South Africa has been experiencing a drought since 2015 and there have been the associated repercussions of losses in some crops, restrictions on water usage and the impact of food and water security (DEA, 2018).

1.3 Maize production in South Africa

Maize is the most important crop grown in South Africa, according to the National Crop Estimates committee (DAFF, 2019). The crop is grown throughout the country under different environments and close to 95% of maize in South Africa being produced by commercial farmers on 87,5% of the cultivated land. The Free State province is the biggest contributor with its output and land planted to maize both being around 40% of South Africa's production (Greyling and Pardey, 2018). The crop's planting dates vary from late October until the middle of December. January is commonly known as "stress month" as the crop is subject to the most extreme heat (Kings, 2019).

Successful maize production is subject to the application of the crop's production inputs (Du Plessis, 2003). These production inputs include adapted cultivars, the plant population, soil tillage methods, fertilisation, weed, insect and disease control, harvesting and the marketing and financial resources available to the farmer (Du Plessis, 2003).

Maize production not only plays an important economic role but is also important to food security. According to Du Plessis (2003), developed countries mostly consume maize as second-cycle produce through meat, eggs and dairy. However, in developing countries, maize is directly consumed. In South Africa, the typical household spends 26% of its food budget on bread and cereals, which is more than meat (25%), milk, cheese and eggs (9%) and vegetables (10%) (Greyling, 2015).

Furthermore, the global demand for maize is expected to be more than the global demand of wheat and rice by 2020 (Leakey et al., 2006). This makes maize not only the most important crop in South Africa but also in the world. It is, therefore, vitally important for the projections and the crop's response to elevated CO_2 to be accurate.

1.4 Problem Statement

With the growing concerns of food security and undeniable evidence of a changing global climate, a lot of attention is directed towards the agricultural sector. Climate change poses the question of what the effect of these changing conditions would have on South Africa's level of agricultural production. The initial opinion is that these changes can only be harmful. This commonly accepted opinion that climate change only has a negative impact on the production of grain crops is, however, flawed. This perception fails to consider that increasing CO_2 levels improve the capacity of plants allowing them to produce more output. If we continue to believe that climate change is only negative, we fail to allow ourselves the opportunity to discover whether the negative consequences of extreme heat and changing average rainfall patterns, can be offset by the positive consequence of CO_2 fertilisation. By rethinking our approach and allowing a comparison between the negative and positive effects of the changing climate, we can reach a solution and discover whether or not the higher levels of CO_2 allowing plants to increase their output, counter the negative impacts of higher temperatures, changes in precipitation patterns and shorter production times of the plants, which would inhibit the production of maize. The research problem is, therefore, the effect of increased levels of CO_2 in the atmosphere on maize plants and its effect on maize production in South Africa.

1.5 Aims and Objectives

The study aimed to investigate the economic impact of the increasing CO_2 levels in the atmosphere on the production of maize and estimate the economic implications that arise due to the higher concentration of CO_2 in the atmosphere.

1.5.1 Aim

To estimate the economic impact of climate change as a direct result of the rising levels of CO_2 in the atmosphere, on the overall production of maize in the Free State province of South Africa.

1.5.2 Objectives

For the purpose of achieving the aims set out for the project, the following objectives are required to be met:

- Evaluate the potential impacts of increased CO_2 as determined by the simulation experiments and how they could impact the production of maize.
- Identify the economic impacts on maize production that arise due to the higher concentration of CO_2 in the atmosphere and the subsequent change in climate.
- Conduct an analysis on individual commercial maize farmers to assess the mitigating factors and limitations placed on them. Additionally, a Market Efficiency (ME) analysis attempts to identify how the effects differ between the eastern and western regions of the Free State province which experience different climatic conditions.

1.6 Method

The project used a positivist paradigm approach (Chilisa and Kawulich 2012) with data from simulation models discussed in the literature review, simulation experiments in CO_2 chambers in the Rhodes University Botany Department as well as an extensive look at industry level maize production. The project used the results from the study in the CO_2 chambers to estimate the impacts at the farm level. The estimation allowed for an analysis on the maize production industry in the province to assess the economic impacts that arise due to a higher concentration of CO_2 in the atmosphere.

The Free State was chosen as the research area as it is the prominent dryland maize production region in South Africa (Greyling and Pardey, 2018). The project focused on commercial maize farmers only as the change in climate can be better explored as there is a more distinctive economic impact on larger maize farmers. A study conducted by Nxumalo (2015) concluded that the size of land is significant in determining the economic impact of climate change. Therefore, sampling is conducted on farms where maize is grown commercially to achieve a profit. As a result, the costs of production and the application of production inputs can be fairly and accurately compared. The analysis assessed the amount of land planted to maize as well as any adaptation, mitigation or any other changes that farmers have had to make to achieve their yields. Sampling was done on 5 farmers in the eastern part of the province and 5 farmers in the western region.

The Rhodes University Botany Department used an open top chamber facility for elevated CO_2, where the level of CO_2 is controlled as well as the amount of water available to the plant. Maize was grown under two concentration levels of CO_2, at 400ppm (parts per million) which is the ambient level of CO_2 and at 800ppm, an elevated CO_2 concentration level. The chambers also included well-watered and drought conditions in their experiments whilst including different cultivars to assess how variations of maize reacted to the CO_2 concentration levels. The experiments showed the response of the plant at different levels CO_2 as well as how that effect differs when the plant is subject to drought conditions or when it is well-watered.

The experiments conducted showed the response to elevated CO_2 and could be used to estimate the expected changes in the yields of grain produced in the Free State. Using the data, scenarios can be created to assess how yield is affected according to water availability and the variety. The scenarios could allow for an estimation of the yield for the different varieties under elevated and ambient levels of CO_2 in drought conditions. These yields can be compared to the yield under elevated and ambient levels of CO_2 when rainfall is sufficient. Through these scenarios, it is possible to estimate what will happen if farmers do not adapt to the changing conditions, the cost of not adapting and if elevated CO_2 is able to offset the negative consequences of climate change.

The impact of elevated CO_2 is addressed in chapter four when analysing the findings of the Rhodes University CO_2 fertilisation experiments. The water saving effect of elevated CO_2 was equated to rainfall. Thereafter, the rainfall figures and production data for the last 10 seasons were analysed to display the potential economic impact of CO_2 fertilisation. Assuming that there is a linear effect on water saving as the levels of CO_2 in the atmosphere increases, the experiments show how this would affect yields.

1.7 Structure

The research project was structured with the following chapters. Chapter one is an introductory chapter where the context of the project is illustrated.

Chapter two is a literature review chapter which discusses climate change and its causes. The chapter gives an in-depth discussion on elevated CO_2 and how it affects the climate and maize plants. Chapter two explores CO_2 fertilisation, increases in average temperatures, rainfall patterns as well as results by previous simulating experiments. The chapter concludes with adaptation methods used by farmers as well as the economic impacts that arise due to elevated CO_2 in the atmosphere.

Chapter three addresses the research approach. The chapter discusses the research paradigm, the methodology and methods that were considered as well as the method that was used.

A background and context chapter are included as chapter four of the research project. The chapter explores the maize industry in South Africa and all the findings of the simulating experiments conducted by the Rhodes University Botany Department are presented.

Results of the study and a discussion of the findings make up chapter five of the project. Chapter five presents the data collected from maize farmers in the Free State as well as the economic impact that elevated CO_2 has had on maize production in the province.

Finally, chapter six wraps up the research project with a summary of the project as well as the conclusion of the research. The chapter also provides recommendations of how maize farmers can optimise their production as well as recommendations to improve research on the topic in the future.

CHAPTER TWO

Climate Change: Causes, Effects and Economic Impacts

2.0 Introduction

The global agricultural sector is faced with the challenge of climate change and the consequences that come with it, in particular, the effects associated with the rising concentration level of carbon dioxide (CO_2) in the atmosphere. Concentrations of CO_2 in the atmosphere have risen by more than 30% in the last century and a half as a direct consequence of human activities and is expected to be doubledby the end of the 21st century if the current patterns of emissions are continued (Tubiello et al., 2000).

However, according to Li et al. (2018), elevated CO_2 concentration can, in a process known as CO_2 fertilisation, increase the net photosynthetic rate of plants to increase yield of agricultural crops through an improved plant capacity. On the other hand, simulations of the future level of CO_2 concentration suggest that there will be a rise in global temperatures, an increase in the frequency of extreme weather events like droughts and floods as well as a change in the precipitation patterns due to the altering of the global hydrological cycle, all of which will impact agricultural production (Tubiello et al., 2000). According to Lobell et al. (2011), trends of changing climatic conditions are large enough in some countries to offset any increases in yields that may come from improved technology, CO_2 fertilisation or any other factors such as adaptation as well as any attempt to mitigate climate change.

The consequences show the impact that the increased levels of CO_2 in the atmosphere could have on the production of maize (*Zea* mays). According to Leakey et al. (2004), the demand of maize globally increased by 45% between 1997 and 2020, making it one of the most important food crops in the world. It is, therefore, vital for the future of the climate and its effect on maize production to be studied.

The impact on the yield of maize is determined by the degree of climate change and the increase in CO_2 concentrations in the atmosphere (Jin et al., 2017). As a result, the effect of CO_2 plays a pivotal role in the future of food security due to the reliance, particularly in developing countries, on grain-based food products. The purpose of this chapter is to explore the effect that the increasing CO_2 levels has on maize plants (C4 plants) and their capacity as well as the economic impact of the expected change in climatic conditions that follow due to the higher content of CO_2 in the atmosphere.

The chapter investigates climate change, the effects of CO_2 fertilisation, the individual and combined effects of increased temperature and drought on crop production as well as the effect of elevated CO_2 on maize quality. The chapter will then investigate the importance and the means of adapting to or mitigating the effects of climate change. Finally, the chapter will close with previous research on the economic impact of climate change on grain production.

2.1 Climate Change

Climate change was defined in chapter 1 as “the observed change in weather data over an extended period of time” (Dore, 2005). A change in the climate is not an unusual phenomenon, however. Paleoanthropology studies suggest that climate does, in fact, change on every temporal scale. However, human activitieshave been found to be altering climate with recent climate data suggesting that climate is becoming more variable. According to Alley et al. (2003), climate changes that are widespread and sudden haveoccurred in the past. These changes in the climate have also had major impacts. However, the probability of climate change being caused by humans has become larger, increasing the chance of radical events to occur. The economic and ecological impacts have the potential to be large if such events ensue.

Evidence suggests that natural systems are being affected by regional climate changes with an increase in temperature being the main culprit (IPCC, 2007). These recent climate changes have started to have impacts on not just natural systems but human systems too. Although, according to the IPCC (2007), these have not yet become established trends, there are cases where this is most definitely the case. An example of such systems being affected, as confirmed by this research paper in chapter 4, is the reduced length of a growing window, which has a detrimental impact on crop production (IPCC, 2007).

In addition to increases in temperature, water availability is a major concern. Bates et al. (2008) claim that records and projections of global freshwater sources are extremely vulnerable which has widespread consequences for the environment and for society.

2.2 Downscaling Climate Models

Downscaling climate models allow for a researcher to derive information on a local or regional scale from a larger model of observed data (Trzaska and Schnarr, 2014). This allows for a scenario to be created for an estimated future date based on the projections of economic and population growth as well as the observed change in climatic data. Climate, however, is a complex phenomenon to try and predict due to fluctuations that occur naturally over time through influences from the natural components of the Earth and its atmosphere (Cooney, 2012). Therefore, downscaling climate models can make climate projections through two ways: dynamical downscaling and statistical downscaling (Trzaska and Schnarr, 2014). Dynamical downscaling uses data and physical measures in models like

Global Circulation Models (GCMs) and statistical downscaling uses established statistical relationships between climate features that GCMs provide and the actual climatic conditions experienced. Statistical downscaling is easier to interpret as they use historical climate observations and the assumptions that the observed data will continue (Trzaska and Schnarr, 2014).

An example of such a downscaling climate model by Engelbrecht et al. (2015) projected the surface temperatures over Africa if no mitigation strategies are adopted. The paper uses a statistical downscaling approach and analysed average surface temperatures over the last five decades to conclude that the surface temperature over the continent could rise by 4-6 ^{o}C over the subtropics and by 3-5 ^{o}C over the tropics during the 21st century (Engelbrecht et al. 2015).

Using these downscaling models, studies can recreate future climatic conditions to estimate the influence the changing climate would have on a crop. Haverkort et al. (2013) used this technique to estimate the effects of land and water use efficiencies on potato production in South Africa from climate change. The study was able to compare the negative effects that the rise in temperature, drought, wind and solar radiation had to the positive effects that came with the higher levels of CO_2 in the atmosphere.

Similarly, Lobell et al. (2008, 2011) believed that the key to anticipating the effect that climate change will have in the future is to understand the impacts of changes in climate to date. The future of southern African crop yields is alarming (Lobell, et al, 2008). The prediction by Lobell et al. (2008) is that by 2030, maize yields for the southern African region will decrease by 30%. The prediction was made through analysing the past relationship between temperature and rainfall and their impact on maize yields. However, the model used, did not account for the positive impacts of elevated CO_2, except for the residual effect that potentially could have been included by the yield responses.

Ripley et al. (2020) did, however, include the effects of elevated CO_2 on maize and the study is discussed in more detail in chapter 4. Furthermore, other studies which do consider elevated CO_2 are discussed later in this chapter.

2.3 Elevated CO_2

Elevated CO_2 is the increase in the concentration of carbon dioxide in the atmosphere. This increase in the concentration of the gas has both negative and positive effects. These effects can be positive through CO_2 fertilisation or negative through climate change (a rise in surface temperature and increases in the frequency of drought conditions). The effects of elevated CO_2 on maize is not sufficiently understood for accurate predictions to be made (Leakey et al., 2004). However, using simulations, several experiments have shown that the effects of elevated CO_2 are different on maize than it is on other crops.

At the current CO_2 concentration, C4 plant photosynthesis should be saturated. Maize is a C4 plant. This means that photosynthesis has evolved such that the photosynthetic process is spatially divided. In the mesophyll cells photosynthetic metabolism uses light and CO_2 to produce a four-carbon organic acid via the enzyme phosphoenolpyruvate carboxylase. This acid is then transported into the bundle-sheath cell surrounding the vascular bundles where it is decarboxylated, liberating CO_2. This CO_2 concentrating mechanism (CCM) elevates the CO_2 concentration in the bundle-sheath cells to 2 – 5 times higher than ambient concentrations. This saturates bundle sheath photosynthesis with CO_2, attaining high rates of photosynthesis. The action of the CCM also means that C4 photosynthesis is relatively unresponsive to increasing atmospheric CO_2 concentrations as the photosynthetic physiology is already CO_2 saturated (Long et al., 2018).

Therefore, in theory, maize should not be stimulated by elevated CO_2 through CO_2 fertilisation (Leakey et al., 2006; Markelz et al., 2011). However, evidence from controlled studies have found that maize has been stimulated under elevated CO_2, although not because of effects on photosynthetic productivity but because eCO_2 results in a water saving (Mandersheid et al., 2014). This conserves soil water and has the potential to increase yields and prolong the growing season.

Elevated CO_2 does also have the effect of changing the climate. Studies on climate change have reported rises in temperature (Kruger and Shongwe, 2004) and higher levels of evaporation, thus, increasing frequency of drought (Benhin, 2006). Higher temperatures and drought conditions both have the potential to adversely affect yields of maize in South Africa.

2.3.1 CO_2 Fertilisation

CO_2 fertilisation is the effect whereby plants absorb more CO_2 when there is a higher concentration of the gas in the atmosphere. This increases the rate of growth of plants as well as their yield due to their effect on the photosynthetic process (Erda et al., 2005: 2151). The first step in this process is due to a photosynthetic enzyme commonly known as Rubisco (ribulose-1,5-bisphosphate carboxylase/oxygenase), which is the main input of the change from carbon into crop biomass (Long et al., 2018). The Rubisco enzyme allows plants to convert CO_2 to energy. The CO_2 fertilisation effect, therefore, is that elevated CO_2 allows for plants to absorb more of the gas due to the higher atmospheric concentrations which provides the Rubisco enzyme the possibility to convert more CO_2 into energy for the plant, increasing the growth rate and yield (Erda et al., 2005).

However, the effect is different depending on the various plant species, average temperature and the availability of water. The different plant species include C3 plants, where the photosynthetic process is most efficient in cool and wet climates, and C4 plants, which are of particular relevance for this literature review and are most efficient in hot and sunny climates (Jin et al., 2017:2688).

The term "C3 plants" is derived due to the first carbon compound produced during the process of photosynthesis and is made up of three carbon atoms (Beery, 2012). C3 plants include crops such as wheat and soybeans which are more suited to cooler climates (Jin et al., 2017) because at high temperatures, the Rubisco enzyme binds with oxygen instead of carbon dioxide which reduces the efficiency of photosynthesis in the plants (Beery, 2012). However, in South Africa where the climate is mostly warm and dry, C4 plants like maize and sorghum are more suitable (Taub, et al. 2010). C4 plants are plants that have evolved to enable a four-carbon atom compound instead of three, which allows C4 plants to bind with carbon dioxide instead of oxygen at high temperatures in specific cells around the Rubisco enzyme. This makes the photosynthetic process more efficient whilst also allowing the plant to be more economical with its water use (Beery, 2012).

Therefore, since C3 plants are not as adapted to warmer climates as C4 plants, photosynthesis of C3 plants is limited to the amount of CO_2 in the atmosphere (Beery, 2012). Due to this limitation, C3 plants tend to benefit more from elevated CO_2 than C4 plants when you isolate the positive impacts to just CO_2 fertilisation. Because C4 plant photosynthesis is not limited to just carbon dioxide, the species of plant tends to be improved by other positive effects which C3 plants do not (Beery, 2012; Ward, et al. 1999). According to Markelz, et al. (2011), whilst C3 plants are limited to the effect of CO_2 on photosynthesis, C4 plants are saturated at current atmospheric levels. As a result, elevated CO_2 will directly stimulate C3 photosynthesis and make up for a fraction of the loss yield due to climate change but the effect on C4 plants is different (Jin et al., 2017). C4 crops are likely to be stimulated by elevated CO_2, not because of the fertilisation effect but because of an indirect effect of improved water use efficiency (WUE) (Leakey et al., 2006)

2.3.2 Temperature

Studies of global climatic conditions and climate change find that the predicted rise in CO_2, one of the main greenhouse gases after water vapour, will cause a rise in global surface temperatures through the greenhouse effect (Tubiello et al., 2000: 180). According to Lobell et al. (2011), since 1950, global temperatures have been increasing at a rate of 0.13 ^{0}C per year. This rate is expected to increase to 0.2 ^{0}C per year.

Year 2015 was the hottest year on record with temperatures 0.9 ^{0}C above the average. It was then surpassed the very next year with a warming of 0.94 ^{0}C above average in 2016 (NASA, 2019). Studies predict that this trend of warming will continue.

In South Africa, Kruger and Shongwe (2004), conducted a study where they looked at 26 climatic stations in the country. Twenty-four of the stations were found to have had a positive trend in the annual average temperature with 18 of the 24 being statistically significant.

Whilst it is established that a higher concentration of CO_2 has the potential to improve the capacity of plants, higher temperatures and the changes to the precipitation patterns that accompany the rise in temperatures also affect the plant photosynthesis process and the yields.

According to Erda et al. (2005), yield is decreased by higher temperatures as the growing time of the plant is shortened. The average soil temperature is critical for plant development with 30 ^{o}C being the optimal soil temperature for maize (Phillips, 2019). Phillips (2019) found that at this temperature during the planting season, the plant has enough time to grow, mature and dry. However, on either side of 30 ^{o}C results have tended to decline. The higher temperatures have the effect of speeding up the development of the plant causing the plant to mature faster. As a result, the period that the plant must produce a crop is shorter. Additionally, Erda et al. (2005) also argued that the effect of heat intensifies the stress placed on the plants during times of drought. Thus, the CO_2 fertilisation process has more negative effects to ameliorate in order to achieve the same yields.

However, according to Jin et al. (2017), elevated CO_2 also has the effect of plants showing signs of higher thermotolerance (the ability of the plant to deal with higher temperatures). Unfortunately for producers of maize, like the effect of CO_2 fertilisation, improved thermotolerance is more noticeable in C3 plants.

Lobell et al. (2011) conducted a study on the effect that increased temperature had on maize in Africa. The results showed for every day spent above 30 ^{o}C the final yield of maize reduced by 1% under good rain conditions and by 1.7% under drought conditions. However, Tubiello et al. (2000) argued that the effect of a change in temperatures on crop production is not uniform. In their research, Tubiello et al. (2000) found that a rise in temperatures may become beneficial in regions where crop production was not previously favourable and harmful in previously prominent regions of crop production. Regions which previously were too cold to produce crops have become warmer and are now more suitable for the crop. Likewise, regions which were known for crop farming have now become too warm. Therefore, the net effect of the rise in CO_2 ultimately depends on the local conditions of the specific region.

Similarly, Olesen and Bindi (2002) reviewed the effects of climate change on agricultural productivity in Europe, finding that, overall, climate change would increase productivity of crops. This is due to the increasing CO_2 concentration and the effects of the CO_2 fertilisation process as well as the improved resource use that follows. However, the research done by Olesen and Bindi (2002) also found that the level of the increase is not consistent throughout the European continent and that in different regions the productivity increase was more radical, resulting in the migration of cropping regions further north. The rise in the temperature caused by increased CO_2 together with effects of CO_2 fertilisation have resulted in the northern regions of Europe becoming more favourable for grain farming. The southern regions, which historically are more suitable and well known for crop farming are facing lower yields, higher yield variability and reduction of suitable farming areas due to the expected water shortages caused by the extreme weather conditions from the higher temperatures (Olesen and Bindi, 2002). The expected intensification of grain farming in the north and "extensification" in the south have caused a migration of the optimum farming regions of Europe to move northwards. As a result, Olesen and Bindi (2002) believe that Europe's agricultural and environmental policies will have to change and adapt to the new regions of grain production on the continent. Economically, the effect of this "migration" is that, although the overall contribution of agriculture to the European GDP may be small, local effects of the shift of the agricultural regions will be large due to the change in the intensification. The economy of Europe experiences little to no change whereas local economies are heavily affected (Olesen and Bindi, 2002: 242).

Leppanen et al. (2014) in their study on cereal crops in Russia confirmed these findings by Olesen and Bindi (2002) and Tubiello et al. (2000) that the rise in temperatures have resulted in the increase in yields of grain production in areas where grain was not previously as successful. Their study found that the increase in winter temperatures have increased the yields of cereal crops (wheat, maize, oats, sunflower and barley) by 1-14% provided that the warming is not more than 2^o C in the country. Rises in temperature of more than 2 ^oC have proven to be less beneficial (Leppanen et al., 2014: 20). This explains why areas in the southern regions of the continent have started to be less favourable for grain production than before as the average temperatures were already suitable for crop growth but are now too warm. Due to the changing climatic conditions these areas are not as suitable as they once were (Olesen and Bindi, 2002).

This issue of regions that are previously favourable becoming less favourable is not only limited to Europe. According to Nxumalo (2015: 21), countries situated on lower latitudes (tropical and subtropical regions) that experience low water availability are at risk of decreased yields. Nxumalo (2015**:** 22) reported that warmer temperatures in the growing season negatively impact the photosynthesis and grain development processes by speeding up the growth of the plant and thus reducing the time that the grain can reach its potential yield.

Drought, discussed in section 2.2.3, is also a result of increased temperature. The extreme droughts that South Africa experiences are often due to the El Nino Southern Oscillation (ENSO) (Baudoin et al., 2017). The year 2015 was marked as the beginning of the "super" El Nino which resulted in one of the worst droughts that the country has experienced. The rise in the surface temperature is what causes the ENSO.

2.3.3 Drought

Water is a basic need for any living organism anywhere in the world (Aslam et al. 2015). Without water, no plant can grow. Drought is the insufficient supply of water to meet plant growth demand and is one of the foremost restrictions on the productivity of crops (Parry et al., 2002). Drought is a difficult phenomenon to pinpoint. Unlike other extreme climatic events which have a definite beginning and end, drought is much tougher to pinpoint when it started or when the period of drought ended (NOAA, 2019). Drought slowly impacts through the absence of sufficient water over a period.

According to Maralian and Ebadi (2010), the area of land around the world affected by drought has more than doubled in the period from the 1970s until the early 2000s. Additionally, the production of cereal crops is increasing every year so the need for water is also increasing (Gevrek and Atasoy, 2012). The availability of water mostly affects the growth of the leaves and the roots of the plant.

Drought in South Africa

South Africa, due to its geographical position, is extremely prone to drought (Baudoin et al, 2017)**.** Located in southern Africa, the extreme droughts that the country experiences are often a result of the El Nino Southern Oscillation (ENSO).

Normal rainfall for a place is calculated by observing the rainfall figures over a 30-year period (SAWS, 2020). Drought, according to the South African Weather Service, is defined when one compares the level of dryness to the average amount of rainfall for that area. If the area receives less than 75% of its normal rainfall the drought is judged to be severe and the South African Weather Service believe that less than 80% results in long term crop and water shortages. This type of drought which is caused by lack of rainfall is termed as a meteorological drought but high temperatures, high wind, low soil moisture and low humidity can also exacerbate the harshness of the drought.

Maize is sensitive to drought and can be affected at various stages of the growth period, from germination to pollination, seedling growth and development of the kernels (Aslam et al. 2015).

According to Jin et al*.* (2017), drought, through its effect of accelerating senescence, has the effect of limiting the leaf expansion and the growth of the root structure, the photosynthetic rate, theallocation of carbon and reducing the formation of the yield.

Senescence refers to the biological aging of the plant and the deterioration that comes with age through the loss of a plant cell's power to result in growth (Prasad et al. 2008). As a result, the plant has a shorter lifespan and, according to Prasad et al. (2008), plants are more susceptible to the negative effects of drought during the production phase of its growth. Jin et al. (2017) conclude that drought is the biggest threat to maize.

The initial response of a plant to drought conditions is to close its stomata to reduce its rate of transpiration (Maralian and Ebadi, 2010). Stomatal Conductance is the measure used to gauge the extent of stomatal opening of the plant. The degree of stomatal conductance is, therefore, used as an indicator of the water status of the plant.

Whilst stomatal closure in response to drought limits the amount of water loss through transpiration, it also has the effect of limiting the amount of CO_2 entry into the leaves and as a result, decreases the opportunity of CO_2 fertilisation through the Rubisco enzyme (Parry et al*.*, 2002). Evidence also suggests that this decrease in the CO_2 intake cannot be undone by a simple increase of the supply of CO_2 (Lawlor, 1995, 2002)**.** Therefore, the negative effect of drought on the Rubisco enzyme and the subsequent CO_2 fertilisation process is not reversed by the higher concentration of CO_2 in theatmosphere.

2.3.4 Combined effect of temperature and drought

Although drought and heat are commonly experienced together, Lobell et al. (2015) believe that distinguishing the role of heat and drought in the losses of yield are important to allow for a comprehensive management strategy when farmers must cope with both stresses.

High temperature and drought stress are among the two most important environmental factors influencing crop growth (Prasad et al., 2011). Higher temperatures increase the rate of evaporation and, thus, have the impact of drought conditions. Lobell et al. (2011) conducted a study where the effects of temperature and precipitation were investigated. The study started by finding that there is a positive trend in temperature and that precipitation patterns were significantly lower in comparison to historical data. Through a regression analysis of historical data, it was discovered that, globally, maize experienced a net loss of 3.8% when compared to what would have been achieved had the climate trends from 1980-2008 remained constant (Lobell et al. 2011). A study conducted by Jin et al.

(2017) found that the heat wave and the drought that ensued in the United States in 2012 reduced the production of maize in the country by 13%.

Temperature and drought have the effect of placing stress on the crop's life cycle, the development and biological aging of the leaves as well as the photosynthetic process and the formation of grain (Jin et al., 2017). As a result, the crop will experience a loss in yield.

Grain filling, which is how much grain each plant produces, explains the loss in yield. As already mentioned in 2.2.3, the negative effects are most dangerous during the development phase of the plant which obviously affects how many seeds the plant will be able to produce. According to Prasad et al. (2008, 2011), plants subject to heat and drought stress produce fewer seeds. Thus, ultimately reducing overall yield. In their 2011 paper, which looked at the independent as well as the combined effects of high temperatures and drought, Prasad et al. (2011) found that under extreme heat, plants have a lower grain filling and the same was found with those plants under drought stress. However, those plants subject to both heat and drought together were the most affected and had the lowest grain filling.

2.4 Effects of elevated CO_2 on maize production

The production of maize will be different due to climate change. Increased temperature, drought and CO_2 fertilisation will all be factors in management decisions to achieve the best possible results (Leakey, 2009). To factor in these impacts of climate change, the responses of crops are simulated in crop models where the variables of water, temperature and CO_2 are controlled.

Jin et al. (2017) simulated the yield of crops using the Agricultural Production Systems Simulator (APSIM). APSIM is a biophysical model used for simulation of crops under different climates whilst being able to integrate data from other models for comparison (Ojeda et al., 2018). The study by Jin et al. (2017) focused specifically on the climatic stress that heat and drought had on rainfed maize and soybean production in the US. As one would expect, the study found that high temperatures and drought adversely affected crop growth and yields. However, high CO_2 levels made it difficult for the study to quantify the effect of the stress placed on the plants by the increased heat and subsequent drought because the increased CO_2 resulted in a rise in the yields and mitigated the strain placed on them by the higher temperatures and insufficient water supply. By simulating an elevated CO_2 concentration, their study found that the effect on the photosynthetic process partially, but not completely, offset the loss of yield caused by the extreme climatic changes.

Similarly, Li et al. (2018) investigated the growth and yield of maize grown in a phytotron (a research greenhouse) under elevated CO_2 concentration but under two irrigation treatments, regular irrigation

(RI) and deficit irrigation (DI). The study found that an elevated CO_2 concentration benefited crops more under DI. The results from Li et al. (2018) are confirmed by a study by Manderscheid et al. (2014), which concluded that CO_2 elevation does not affect crop yield unless there is a drought. This conclusion was based on Free-Air Concentration Enrichment (FACE) experiments, which, unlike previous studies conducted in protected environments like greenhouses, are open-air field trials. Therefore, a more realistic simulation (Leakey et al., 2006: 779). These FACE experiments are conducted in open fields where the plants are exposed to the current conditions that the region is experiencing whilst allowing those conducting the study to control the level of CO_2 (Dietterich et al. 2015). Manderscheid et al. (2014) tested the hypothesis that under sufficient water conditions, maizegrowth does not respond to elevated CO_2 levels. The study was conducted by growing maize over twoyears (2007 & 2008) under sufficient and insufficient water supply as well as under ambient and elevated CO_2 concentration levels.

The study by Manderscheid et al. (2014) not only investigated the effect on the yield under the differing conditions but also the water use efficiency (WUE). WUE, according to Li et al. (2018: 72), looks at the amount of water that the plant uses compared to the amount the plant loses through transpiration. Manderscheid et al. (2014) found that WUE was hardly affected under sufficient water supply conditions but under insufficient supply there was a strong effect on the WUE as the plants were losing less water through transpiration and, therefore, making more efficient use of the water it was receiving. The conclusion of the study was that, although the effect of drought is not completely offset by higher CO_2 concentration, economic yield and WUE increase.

However, Leakey et al. (2004) conducted a similar study to that of Manderscheid et al. (2014) using FACE experiments. The study looked at the US Corn Belt which typically receives relatively high rainfall and has deep soils which make the region relatively favourable to produce grain. The purpose of the study was to reassess the view that the photosynthetic rate, under favourable growing conditions, would not be increased by elevated levels of CO_2 concentration, particularly for C4 plants. The result of the study contradicted this belief as rainfall for the year that the study was conducted was close to the average rainfall for the region (therefore, not a drought year) yet the elevated CO_2 concentration in the atmosphere still resulted in increased capacity of the plant as increased CO_2 uptake and lower transpiration were still measured. In a later study conducted by Leakey et al. (2006), which also conducted a FACE experiment, it was believed that maize yield is stimulated under drought conditions, not because of an increase in photosynthesis, but because of an indirect effect of water savings and increased WUE by the plant. What this study showed was that the effect of higher concentrations of CO_2 stimulates the photosynthesis process in both favourable and unfavourable conditions but WUE is increased thus increasing the capacity of the plants in unfavourable conditions more.

Rosenzweig and Tubiello (2007) found a similar conclusion to that of Leakey (2004) saying that rainfed maize has a higher yield response to a change in CO_2 concentration levels than irrigated maize. However, although the change in yield under ambient and elevated CO_2 levels is more quantifiable under no irrigation and unfavourable conditions, yields are still higher under irrigation and favourable growing conditions (Rosenzweig and Tubiello, 2007).

When reviewing the results of simulating experiments one can conclude that elevated CO_2 will partially offset the loss in yields caused by extreme climatic conditions like drought and heat. This is aconclusion supported by Lobell et al. (2015).

However, elevated CO_2 does complicate the process of quantifying the effect of heat and drought. Along with the studies mentioned above, Long et al. (2006); Bernacchi et al. (2007); Leakey et al. (2009); Bunce (2014); Madhu and Hatfield (2014); Hussain et al. (2013) and Urban et al. (2015) all agree that elevated CO_2 reduces stomatal conductance which results in a lower transpiration by the plant and an increase in the soil water content. This offsets the potential stresses placed on the plant by drought and benefits yield.

Yet, despite findings that the negative effects of climate change have the potential to be offset by elevated CO_2, overall projections of future crop yields indicate a decrease in production (Leakey *et al.* 2009). The effects of CO_2 only partially offset the negative effects, so adaptation of farming practices is still required (Lobell *et al.* 2008)

2.5 Grain Quality

Although CO_2 fertilisation is said to improve plant capacity and the resource use efficiency, further studies have been conducted to investigate whether the quality of grain produced remains at the standard of crops that are grown under a less concentrated level of CO_2. Myers et al. (2014), in a replication of climate similar to some of the previous studies above, used FACE technology to simulate the growth of various crops under different levels of CO_2. Unlike the other simulations though, Myers et al. (2014) not only attempted to quantify the change in levels of production, but also the change in the quality level of the crops. The study was conducted by analysing samples of wheat, maize, soybeans, sorghum, field peas and rice under ambient and elevated levels of CO_2 over a 12-year period. Interestingly, the results showed that the content of zinc, iron and in some cultivars, protein, decreased under an elevated level of CO_2. According to Dietterich et al. (2015), this decrease in quality is more prominent in C3 species plants but C4 plants still are found to have decreased grain quality. Investigations conducted prior to Myers et al. (2014), studies attempting to measure the changes of plant nutrition have found that, besides nitrogen levels, there has been little change in the nutritional make-up of the plants. However, Dietterich et al. (2015) believe that this is simply because these results were obtained because the study unintentionally limited nutrients in the plant by growing them in pots. Subsequent experiments have also lacked a large enough sample size to challenge the findings of Myers et al (2014) as the findings cannot be said to be meaningful due to the much smaller scale of the study.

2.6 Adaptations to Climate Change

Lobell *et al.* (2008) identified the need to adapt as a key factor in shaping the future impact of climate change on crop production, and ultimately on food security. South Asia and southern Africa, particularly in wheat and maize production respectively, are the two regions and crops which they believe could suffer the most detrimental effect on crop production without adopting adaptation methods. Dryland grain production relies on adaptation, and according to Dean (2018), in an article written in "Farmer's Weekly" magazine, commercial farmers can not only survive the harsh conditions but also grow their production through adaptation.

Adaptation, according to Schulze (2016), is the process whereby the global agricultural sector takes steps to cope with the uncertainty of the future climatic conditions. These steps involve measures of adjustment and changes that reduce the negative effects of climate change or take advantage of the positive effects. The level of adaptation is vital in assessing the economic impact of the changing climate on grain production. If done efficiently, it can improve yields and therefore, income, but also adds an additional expense to the farming operation, which would have to be incorporated when calculating net income.

These adjustments that Schulze (2016) refers to could be made to management strategies, responding to actual and expected climatic changes through enhancing the resilience towards the changes and reducing vulnerability and ultimately exploiting the opportunities that could prove to be beneficial. Nxumalo (2015) expressed that in order to achieve optimum results, there needs to be an understanding between the adaptation method or the management strategy chosen and plant physiology. Being unclear of the effect on the plant could lead to inefficient adaptation and therefore additional expenses whilst remaining at a lower level of production. Smit and Skinner (2002) reinforced the need for adaptation techniques to be implemented astutely in their typology about the different adaptation options available in the agricultural sector. Smit and Skinner (2002) not only recognize the necessity to understand the impact on the plant itself but also the relationship between the adaptation option and the existing processes being used.

The adaptation techniques do, however, come at a cost to combat the changing conditions. Adaptation could be done inexpensively, by changing the dates in which these crops are planted or the intensity of the crop production (Finger, Hediger and Schmid, 2011), or expensively by developing new varieties that are conducive to the new climatic conditions, expansive irrigation or adapting the use of fertilisers and pesticides to the changing climate (Ghahramani et al, 2015), which would require substantial investment by the farmer or the state. The economic decision in monetary terms between the inexpensive or expensive methods, is quantified through how much the change is expected to be, compared with how much of an impact and improvement the adaptation method has had (Schulze, 2016).

Finger et al. (2010), in a study on the effect of climate change on the Swiss maize production, investigated the adaptation options of changing the dates in which plants are planted and sowed as well as changing the intensity of production. To conduct their study, Finger *et al.* (2010) used a CropSyst model that simulated the relationship between current as well as future climatic conditions in the region. The CropSyst model is a cropping simulation model that is conducted over several years to study the effect of the climate and management techniques have on the productivity of crops (Stockle et al, 2003: 290). The model is applied to measure the risk and economic benefit (if any) of climate change, applying different systems of cropping and different management techniques (Stockle et al, 2003: 289).

The CropSyst model used by Finger et al. (2010) incorporated three different scenarios of climate change (temperature, precipitation and CO_2 concentration). The study identified that with the use of these simple adaptation methods there was little impact of climate change on maize production. However, rainfed maize was found to have increasing yield variability and this was expected to continue in the future. Therefore, further adaptation in the form of irrigation was tested and it was found that yield increased and variability between seasons' yields decreased. According to Finger et al. (2010), the economic benefit of the irrigation adaptation method is not only reliant on climate changes but also on the market prices of maize and the effects of water pricing. Their study concluded that there is a small economic benefit of irrigation due to market liberalisation driving prices down and the cost of water expected to rise. Although Leakey et al. (2006) believed that because plants' WUE increased showing a greater quantifiable positive impact of higher CO_2 levels under unfavourable conditions, the fact that yields increase and show less variability under irrigation make this adaptation method one that is economically worth pursuing (Schulze, 2016). According to Parry et al. (2004), the increased temperatures associated with the higher levels of CO_2 allow for the growing season to be much longer. The longer season due to the rise in temperature allows for the adaptation method of changing the dates in which crops are planted and sown to be adopted relatively easily.

Prior to Finger et al (2010), Tubiello et al. (2000) conducted a similar study using the CropSyst model. The study considered the doubling of the level of CO_2 concentration in the future and the effect it would potentially have on the agricultural production in two Italian locations. Their study investigated the impact of certain adaptation methods and found that early planting for crops grown over spring and summer as well as using a cultivar that takes longer to mature were the most successful methods in maintaining the current yields under future expected CO_2 concentration levels. The model found that to keep up the current yield using irrigation, 60-90% more water would need to be used as the increase in temperature drives the water loss beyond the saving due to eCO_2. This brings into question the cost of irrigation being used as an adaptation technique in the future, especially for water poor countries. The study did conclude, however, that the negative effects of climate change can be debilitated through simple management techniques in management and through breeding of resistant cultivars.

Additionally, one successful adaptation strategy that is employed by farmers is to increase their production levels. Dean (2018) gave an example of this through a farmer who increased total grain production from 280 hectares to 9200 hectares between 2002 and 2018. The idea behind this is to make use of economies of scale which allows the farmer to be able to make enough of a profit in a poor year to at least guarantee the ability to produce again in the next season.

However, the underlying finding when discussing adaptation, is that the development of maize varieties which are more drought tolerant is the best option (Muralian, et al. 2010). Drought tolerance as an adaptive strategy allows the plant to maintain its physiological processes under drought stress which allows for a higher economic yield (Aslam, et al. 2015). Seed companies such as Monsanto and Pioneer (amongst others) work on all aspects of maize crop research with drought tolerance being one of the key research areas.

2.7 Mitigation

Adaptation is not the only method in which the effects of climate change can be reduced or exploited. Rosenzweig and Tubiello (2007) tested mitigation strategies in the agricultural sector. Agriculture is believed and expected to be one of the most affected sectors of the global economy by the increase of greenhouse gases in the atmosphere. However, the sector is also one of the main reasons for the rise in the concentration of these gases causing the changing climate. Therefore, the sector may need to adjust through mitigation strategies. These mitigation strategies include reducing the level of greenhouse gases being emitted, carbon sequestration and interactions of adaptation methods with mitigation strategies. Like adaptation, mitigation strategies are relevant to this literature review as they would require a change in management strategies by the farmer which ultimately affect their net income.

Through conservation agriculture (CA) (discussed in more detail in Chapter 4) farmers can mitigate their emissions of CO_2. According to Cornell University's website on conservation agriculture, CA takes shape in many forms. One of these is the limited mechanical traffic over soils resulting in farmers emitting less CO_2 in the atmosphere. Rosenzweig and Tubiello (2007) believe that by reducing the on-farm emission of greenhouse gases the effects of climate change can be slowed. However, because climate change is unavoidable and global CO_2 is rising regardless, the study investigated the mitigation strategy of carbon sequestration. Carbon sequestration involves the process of storing higher levels of carbon in the soils to exploit the positive effects of CO_2 fertilisation. The use of cover crops, better management of soils and varieties of crops with a high biomass production combined with a low tillage system are suggested by Rosenzweig and Tubiello (2007). However, a reduction in emissions has the added economic benefit of lowering costs of production as it allows the farmer to spend less on fuel.

Solomon et al. (2000) found in their study conducted in sub-Saharan Africa that improvements to the efficiency of irrigation had a large effect on the levels of crop production under the unfavourable crop conditions of the region. Rosenzweig and Tubiello (2007) continued with this and believe that an interaction between the adaptation methods of irrigation (as suggested by Solomon et al. (2000)) and fertilisation with mitigation strategies of carbon sequestration would improve capacity in regions that are less favourable to crop production.

Rosenzweig and Tubiello (2007) concluded their study believing that adaptation should take precedence over mitigation as climate change is already happening and the synergy between adaptation and mitigation is not possible under all climates.

2.8 Economic Impact

The economic impact of climate change is measured through gross margins. In order to calculate the gross margin, one needs to subtract the direct costs of producing a crop from the sales revenue ultimately obtained (Nxumalo, 2015). The costs associated with crop production are variable and dependent on the quantity produced. These costs include the inputs required like transport, labour, land preparation, fertilisers, seed, chemicals as well as any costs from adaptation or mitigation techniques adopted (Nxumalo, 2015).

Nxumalo (2015) conducted a gross margin analysis on the effect of climate change on farmers in a region of the Kwa-Zulu-Natal province. The farmers were producing on a relatively small scale so the costs incurred are obviously relatively low, and therefore the gross margins will be lower, in comparison to a study conducted by Ghahramani, et al. (2015) on the effect of climate change on wheat farming in Australia, which was on a much larger scale as it looked at the entire wheat production system in the country. Nxumalo (2015) used a multiple regression model and a Ricardian model in the investigation to assess the impact of each variable individually and overall before calculating the net income of the farmers, after all the considerations in the gross margin analysis were included (Nxumalo, 2015).

The independent variables included in the multiple regression were the age of the farmer, their level of education, their access to credit, the size of their land, their experience as a farmer, the type of soil in their region, whether irrigation was used, whether there was use of fertilizer and the yield the farmer obtained in the previous season. The variables were used to test the impact that each of them had on the gross margin (Nxumalo, 2015). For this literature review the use of irrigation and fertilizer as well as the previous season's yield are of relevance to calculate the effect of disruptions of farming operations due to climate change referred to by Schulze (2016).

For the Ricardian model, Nxumalo (2015) included the variables used in the multiple regression as well as variables that are direct consequences of the changing climatic conditions. These variables include the level of precipitation in the various seasons (Winter, Summer, Spring and Autumn) as well as the temperatures in those seasons. The Ricardian model analysed the relationship between the inputs (and therefore the costs associated with them) and the outputs achieved by regressing the climate variables (Nxumalo, 2015).

The results of the gross margin analysis conducted found that the net income, on average, of farmers growing maize in dryland were significantly lower than those using irrigation (Nxumalo, 2015). The results are expected and correlate with Lobell et al. (2006) identifying adaptation methods like irrigation to be vital in the future of grain production globally. The results of the gross margin analysis, albeit on a relatively small scale of farming, showed that farmers using irrigation were earning R5444 more than dryland farmers, on average.

Ghahramani et al. (2015) conducted their study by analysing the yields and gross margins of the production of wheat under the current climatic conditions in Australia as well as the projected conditions. The results were then compared with best yield achieved using adaptation through adjustments in planting dates, nitrogen fertilizer and differing varieties. Their study evaluated the impact of climate change and adaptations in terms of the yield obtained per hectare and the gross margin per hectare. The gross margin in Ghahramani et al. (2015) is the difference between the estimated income and the costs of production. The gross margin found was then compared to the adapted gross margin which took the different yields and additional costs into consideration. Gross margins through a use of adaptation increased with the growth ranging across the country. The average increase being around 20% higher than the gross margin achieved without efficient adaptations.

2.9 Conclusion

The findings of the chapter observe that the concentration level of CO_2 in the atmosphere is rising and is expected to rise in the foreseeable future due to lacklustre efforts to change the human activities that are emitting CO_2 and thus having an impact on the climate (Tubiello et al, 2000). A higher level of CO_2 in the atmosphere is found to have both positive and negative effects on the production of grain (Nxumalo, 2015). Initially, it was found that the effect that CO_2 has on increased temperatures, changing precipitation patterns and increase in extreme weather events is detrimental to the global production of grain as well as the quality of the grain that is being produced (Leppanen et al, 2014). However, through a process known as CO_2 fertilisation, which increases the capacity of plants by impacting the photosynthetic process through a lower transpiration rate, plants are making more efficient use of resources and the negative effects of the changing climate are partially offset (Leakey et al, 2006).

Following these findings of the positive effect of increased CO_2 through CO_2 fertilisation and improved WUE, the detrimental consequences of rising temperatures and changing precipitation patterns, the literature acknowledged that the agricultural sector is in need of adaptation techniques to allow farmers to potentially exploit the opportunities that arise from climate change and use them to their advantage as well as to limit the damage caused by the negative consequences (Lobell et al, 2006). These adaptation techniques could be relatively simple and cost-effective or more expensive and expansive techniques. The costly techniques were found to have a bigger impact on the yield but in only some circumstances is the higher yield also associated with a much higher economic yield.

Finally, the changes in yields due to higher CO_2 concentrations as well as costs associated with adapting can be measured through conducting a gross margin analysis (Nxumalo, 2015). The gross margin analysis reported on in the literature review both found that gross margin increased provided adaptation techniques were used.

CHAPTER THREE

Research Approach: Paradigm, Methodology and Methods

3.0 Introduction

This chapter addresses the aim of the research project, the design and the research tools considered and used to achieve the aims set out. Additionally, the chapter addresses the collection of the data used for the study and the procedures followed during the data collection process. Furthermore, the chapter discusses the research paradigm and analyses the methodology and methods. Lastly, previous studies using similar methods are briefly discussed.

3.1 Aim of the study

The opening chapter of the research project introduced the economic effect of climate change on maize production and how, economically, it is made up of a contrast. The contrast is between the positive effects that climate change brings through CO_2 fertilisation and their improved resistance to stress (Erda et al., 2005; Jin et al., 2017; Olesen and Bindi, 2002; Tubiello et al*.,* 2000; Nxumalo, 2015; Li et al*.,* 2018; Manderscheid et al*.,* 2014) and the negative consequences of extreme conditions and changing precipitation patterns (Erda et al., 2005; Tubiello et al*.,* 2000; Lobell et al., 2011). The theory by Schulze (2016), that the costs incurred of adapting to the new conditions being the crux of the economic debate is what this chapter aims to quantify.

With the considerable amount of literature available on the effects of elevated CO_2 on maize plants, understanding that there are positives to the rising levels of the gas in the atmosphere is established. However, what the impact that these changes are having on the maize industry is a topic that needs review. The economic impact of the ever-changing climate on the production of maize is poorly understood. These impacts, however, are not just limited to the additional costs of production, but the change in the makeup of the industry.

However, Stern (2007) believes that climate change is the greatest and widest ranging market failure that has ever been reviewed and as a result, a unique challenge is presented to the world of economics. The economics of risk and uncertainty of climate change must, therefore, also be highlighted. Although it is impossible to predict the consequences of climate change with complete accuracy, enough is known to understand the risks associated with it.

The study aims to investigate these risks through the economic impacts of the increasing CO_2 levels in the atmosphere on the production of maize. The study attempts to estimate the economic implications that arise due to the higher concentration of CO_2 in the atmosphere.

3.2 Study Design

The study made use of a mixed methods approach through the collection, and analysis of quantitative and qualitative data (Cresswell and Clark, 2007). Originally, the study was only going to use quantitative data within a post-positivist paradigm (Chilisa and Kawulich, 2012) approach. The post-positive paradigm was chosen due to the nature of the research whereby the aim was to attempt to quantify the effect of climate change and, therefore, quantitative data was going to be used throughout the research process.

Yet, as the study took form, it became apparent that to accurately represent the economic environment of the maize industry as a result of climate change, qualitative data would also need to be included. Through the mixed methods approach, the study was afforded the opportunity to integrate quantitative and qualitative data (Steckler et al. 1992).

Quantitative methods came from simulating experiments and case studies which are represented in monetary figures, tables and graphic representations. Interviews and questionnaires allowing for personal experiences and opinions were conducted with commercial maize farmers and included as qualitative methods.

The project was designed to make use of the Ricardian model but due to time and funding constraints and the large data set that the model requires, a conclusive and comprehensive use of the model was not achievable or realistic. However, the principles behind the model were maintained and formed the basis behind the structure of the research and the conclusions drawn from the data collected. Although the Ricardian model was not used in its entirety, it is recognised that the approach is the ideal method to use in order to achieve the most accurate estimate of the economics behind the change in the climate and how it is affecting the production of maize in the Free State. As a result, the principles behind the model were maintained and the study was based on these principles.

Pedersen et al. (2005) used a gross margin analysis to examine the different potato production regions in the European Union. This project adopted a similar approach where the different crop practices across the two selected production regions of the Free State were highlighted as well as their cost structures and finally their gross margins.

3.3 Primary data collection

The study used two sets of data collection. Firstly, simulating experiments and secondly, commercial farmers were interviewed. The results and findings of these two sources are included in Chapter 4. The simulating experiments were conducted in 2019 and the results of the experiments are explored in chapter four. Data collection, in the form of case studies, were conducted during the 2019/20 planting season and the findings are also found in chapter four. The results of simulating experiments and case studies are contrasted to see whether there are any similarities between the simulating experiments and the economic findings. The objective of including case studies in the project was to attempt to estimate economic values and economic impacts to the simulating experiment findings**.** This technique also allowed for a practical contrast of the positive effects of CO_2 fertilisation with the negative consequences of climate change. The simulating experiments show what is expected to happen whilst the case studies show what is occurring at industry level.

3.3.1 Simulating experiments

Simulating experiments were conducted in the Rhodes University open top chamber facility for elevated CO_2 as T. Bobape's MSc study. The chambers make use of two levels of CO_2, 400 ppm which is similar to the current level of atmospheric CO_2, and 800 ppm, which is what the atmospheric level of CO_2 is expected to be by the end of the 21st century at the current rate of global emissions (Tubiello, et al. 2000 :179). The experiments also made use of two different water regiments. The experiments can observe the changes in the maize plants under different conditions. Through the simulating experiments the effect of water, variety and region on the yield could be investigated.

The data from the experiments can show the potential economic impact of elevated CO_2 on maize. Through analysing the findings of the experiments, the production data over the Free State province over a period of 10 years and the rainfall data for those 10 years one can identify how the amount of rain impacts production. The economic impact of the elevated CO_2 and the water saving effects that it has on maize can be measured.

3.3.2 Farmer questionnaire

The farmer questionnaire consists of 19 questions. The questionnaire gathered information on the varieties of maize planted, the yields achieved, the costs incurred by the farmers as well as their returns allowing for their profit margin to be analysed. Additionally, the questionnaire also investigated the management strategies of the farmers. These strategies included their cropping techniques (zero, reduced or conventional tillage) and adaptations they have made or adaptations they are considering making. The questionnaire also allowed for the study to discover what climate factors were the most impactful as well as whether the adaptation methods used are worthwhile. Lastly, the farmers were provided an opportunity to give their opinion on any factors that the study is neglecting or how the research could be improved in the future.

3.4 Secondary data collection

Secondary data was collected from various online sources similar to the simulating experiments conducted by the Rhodes University Botany department and economic studies that this research paper attempted to achieve.

Online sources were used to gain an understanding on the effect of elevated levels of CO_2 (eCO_2) and how they affect maize plants and the climate. Additionally, the economics of climate change was better understood. Through these sources the questionnaire was designed.

The impact of eCO_2, through the secondary data collected, was established to benefit the water use efficiency (WUE) of the maize plants, and in some cases completely offset the negative consequences. The data also showed the importance of adaptation to climate change and, unfortunately for farmers, the costs that came with adaptation. The secondary data gave credibility to the findings of the primary data. According to Stewart and Kamins (1993), the secondary data can make the primary research more valuable as it gives access to data which is of a higher quality and more representative.

3.5 Questionnaire design

The questionnaire was designed to allow for quantitative and qualitative data to be collected. The farmers were given an opportunity to share their personal experience and opinions on how their production of maize has changed as the climate has changed. In addition, the findings of the Rhodes University simulation experiments and other experiments included in the literature review (Chapter 2) were shared with them and asked whether they believed these were accurate for their particular farm which gave the research some qualitative data to include in the study.

However, for the study to achieve the aims it set out, quantitative data needed to be collected. Farmers were also asked about the productivity of their farm and the costs that they incur. The quantitative data is in the form of real figures to give statistical integrity to the results of the study.

3.6 Sample and representation

The data for the project was collected after the planting period for the 2020 season between 30 December 2019 and 30 January 2020. Only commercial maize farmers were included in the study as they are affected by the effects of the changing climate and could, therefore, relate their experiences and how they have had to manage the effects. The study could be considered to be biased due to the fact that small, subsistence farmers were not included but the objective was to simply investigate and to estimate the economic impact that climate change has had and this was considered to be more accurate and easily attainable through commercial farmers.

In total 10 farmers were included in the study, 5 from each of the two study regions. Although this is only a handful of farmers when one considers how many maize farmers there are in South Africa, it does give an idea of the very real effects that farmers are facing and the changes they and their fellow farmers are experiencing. For this reason, the farmer study is only considered to be a case study and does not assume that the findings are the same for every maize farmer in the Free State province

All the farmers included in the study had secondary sources of agricultural production other than maize.

3.7 Ethical Considerations

Due to the project requiring sampling to be done on maize farms in the Free State, there were ethical considerations to consider in all encounters with the farmers. The research project was given ethical clearance by Rhodes University and all participants in the study were offered the opportunity to request the clearance certificate either before or after the research was conducted. Participants were reminded that their participation was voluntary and that they could withdraw from the research project at any time should they so wish. The risks associated with their participation were low, however, the participants were made aware that their participation would remain confidential, nonetheless. Although the data they gave would be published, their names and contact details would not be made available to anyone outside of the researchers directly involved in the research project. Additionally, the participants were offered to have an electronic copy of the completed project emailed to them to allow for complete transparency. While conducting the research all the requirements of the Rhodes University Ethical Standards policy were recognised and met.

3.8 Methods and Methodology

The method refers to the research tool the project will use in order to quantify the impact of climate change on the production of grain in South Africa (Chilisa and Kawulich 2012). This includes a strategy to choose variables and components of study that make logical sense in the context of the research area and have an impact.

Through the data collected, the research project was able to identify the extent of additional costs farmers have to incur in order to produce a crop in the current climate as well as their costs in adapting to the new climatic conditions to take advantage of, or limit the damage caused by the higher levels of carbon dioxide in the atmosphere. The model also allows data to be collected on additional variables that may have an influence on the net revenue of the crop.

Data was collected where grain farming operations are on a large scale, and, additionally, irrigated and dryland production were treated separately (it is assumed that the choice of the two farming systems is exogenous). The variables that were considered fall under the following subsections:

- Size of cultivated land in hectares
- Gross production
- Direct variable costs
- Indirect variable costs
- Yield
- Output in Rands

Size of cultivated land

The project examined commercial maize farming only, that is, crops that are grown for the purpose of producing an income for the farmer and to support the population's food needs. The size of cultivated land, therefore, is important as commercial crop farming is generally conducted on a large scale. The scale of the farming proved to be significant and is discussed in chapter 4.

South Africa has a production structure that is very concentrated, in that there is a relatively small core that is responsible for a large portion of commercial grain production (Greenberg, 2015). The size of cultivated land is a factor of production and the effects of climate change, even marginal, can have a large economic impact.

Gross production

Gross production is the total output from the production process and includes variables that provide a benefit to the farmer but are not necessarily measured and included when measuring the output of a crop to a commercial farmer (Sibanda et al*.*, 2016: 7). These include consumption by the household, any donations that may be given, use of the crop as feed for livestock or for seed in the next growing season.

Direct variable costs

Direct variable costs are the costs that are directly attributable to the production of the crop. These costs include the cost of seed, herbicides and pesticides, crop insurance, marketing costs, transport, packing materials, miscellaneous costs and any costs arising from adaptation to climate change in the form or fertilisers, irrigation, changing planting and harvesting dates, change of farming practices, introducing hybrid seeds and any other practical adaptation technique used that influences the output. These costs also include the purchasing of additional equipment or increasing the scale on which the farmer is producing maize.

Indirect variable costs

Indirect variable costs are variable costs arising that are not directly allocable to the production of grain. These costs include fuel for vehicles and machinery, repairs, spare parts, electricity and any other costs arising for the farm provided they have a practical purpose in the business**.** Farmers who produce maize under irrigation, for example, would accrue higher indirect variable costs as their electricity costs tend to be higher than those of dryland farmers.

The costs, either direct or indirect, were included under one blanket term, costs of production, when the interviews were conducted. It was felt that whether the costs incurred were direct or indirect was irrelevant as they still are an economic burden to the farmer. What was relevant was the increase or decrease in the amount of funding necessary to produce maize in the current climate.

Yield

This is simply the total yield produced in a season by the farm per hectare. These can be compared to previous seasons to analyse whether the farmer is improving yields from season to season. The trend can show whether having larger previous yields will benefit a farmer, if continuous low yields are hampering the farmer's growth in the market or how much their yields are increasing or decreasing as the climate changes.

Output in Rands

The value of the output in Rands. Also referred to as the gross value of production and is found by multiplying the yield by the market price. This gives the total income to the farmer from a single season of grain production. The output is measured in Rands to calculate the economic impact of the changing climate. Furthermore, for the gross margin to be conducted the output must be in monetary terms.

Data was collected based on the sub-sections above and captured for analysis. The data was used to calculate the gross margin which is found by subtracting the direct costs for production from the sales revenue. Costs vary with the scale of operation. The gross margin gives an estimation of the changes in farmer's incomes in relation to their scale of production (Abdullahi et al. 2017).

The data was captured and analysed on Microsoft Excel. The points of interest were the gross margins of each farmer, their costs of production, their production and income per hectare of maize that they plant and the impact that their scale of production has.

3.9 Gross Margin Analysis

Whilst the Ricardian Model principles were used in the questionnaire and the approach of the research, a gross margin analysis was conducted to determine the costs, returns and net profit of the farmers included in the case study. Through the gross margin analysis, the efficiency of the production can be analysed, and whether the market itself is efficient (Abdullahi et al, 2017).

The gross margin is simply the variable costs of an enterprise subtracted from the output (Abdullahi et al. 2017). It is important to note that the gross margin is not the profit of the enterprise. When one conducts a gross margin analysis the figures should only be compared to an enterprise that has similar characteristics. This allows for the study to be able to conclude on the economic and production efficiency of the enterprise (Abdullahi et al. 2017). Taking this reservation into account, once data was collected from the research areas it became apparent that maize farmers from the west had quite different characteristics to the farmers in the east. It was, therefore, decided that farmers could be compared within the same region but not across the two regions.

The gross margin is expressed in the following equation given by Salako et al (2013):

$$GM = TR - TVC$$

However, profit (π) is expressed as:

$$\pi = TR - TC$$

where,

GM = Gross Margin

TR = Total Revenue

TVC = Total Variable Costs

TC = Total Cost = TFC + TVC

TFC = Total Fixed Cost

Lawrence (1992) believes that the gross margin is the first step that is necessary to provide information that would refute the misunderstandings that arise when the performances of a market are analysed. In an agricultural sense, gross margins are useful for planning as it is easy to compare to similar enterprises achieving better profits.

The gross margins of each farmer were thus calculated and compared across the relevant region. This allows for the most efficient production to be revealed.

Whilst the gross margin allows for the most efficient production to be found, it does not reveal the market efficiency of the region. Market efficiency is given by the equation (Shephard et al, 1982):

$$ME = {}^{\text{Costs of Production}}\!/_{\text{Revenue}} \times 100$$

Where,

ME = Market Efficiency

Market efficiency is a coefficient that shows the percentage of the revenue taken by the costs of production. Therefore, the lower the coefficient the more efficient the production is. The average efficiency across the region is therefore assumed to be the efficiency of the region.

According to Jabir et al. (2009), In a perfectly efficient market, all the farmers will have implemented the most efficient adaptation and production methods. However, in agriculture it is impossible to assume a “one size fits all” model because there are so many variable factors between farms, so the most efficient production method is subjective. However, the marketing efficiency does allow the project to see the most efficient region.

CHAPTER FOUR

Background and Context

4.0 Introduction

Maize is the world's most widely grown crop with around 1 billion tons of maize produced each year around the world. This makes up about 38% of the annual global grain production (Farmer's Weekly, 2018). South Africa achieved its biggest maize production in the 2016/17 season, producing 16 744 million tons (GrainSA, 2020). The Free State province is the country's biggest contributor to maize production averaging close to 40% of the annual production (GrainSA, 2020). Additionally, the crop is the source of the staple food and food security of the majority of sub-Saharan Africa (Mulungu and Ng'ombe, 2019). However, climate change threatens the agricultural potential of the continent and, therefore, poses a risk to food security in the future. Of particular interest is the impact it may have on South Africa.

This chapter explores maize production in South Africa by looking at the biggest contributors, the climatic requirements for maize which reveals why maize is more successful in the highveld areas of South Africa. Additionally, the chapter looks at previous studies which have explored the effects that climate change has on maize production as well as the simulating experiments conducted by the Rhodes University Botany Department on the effects of elevated CO_2 on maize.

4.1 Climatic Requirements

Maize is a versatile crop which is grown across differing conditions across the country. The success of the production is dependent on the correct application of inputs such as cultivars, plant population, fertilisers, tillage and weed and pest control. Whilst maize is versatile enough to be able to be produced across the country, there are some climatic requirements which allow the crop to be more successful in certain regions.

4.1.1 Temperature

Maize is more successful in regions that experience a warm climate. According to Du Plessis (2003), the crop requires an average daily temperature of around 19 ^{o}C and an average monthly temperature of at least 23 C^{o} in the summer months.

The seeds can germinate at temperatures of around 10 ^oC but will be more consistent and quicker at soil temperatures of 16 - 18 ^oC. However, there is a negative impact on yield at temperatures exceeding 32 ^oC (Phillips, 2019; Du Plessis, 2003).

On the other end of the scale, extended cold periods can have a negative effect on the growth of the plants. According to Jaidka et al (2019), periods of cold below 5 ^oC for long periods can have a severe impact on the maturity of the plant. In the main production areas of South Africa, frost is a serious problem which farmers face (SAWS, 2020). Frost tends to damage plants and declines the potential yield. Maize, therefore, requires between 120 to 140 days with no frost to ensure that plants mature fully (Du Plessis, 2003; Farmer's Weekly, 2018). Maize farmers in South Africa, therefore, have to plant the crop late enough in the year so that it will be warm enough for the plants to germinate whilst simultaneously providing enough time for the spring rainfall after the dry winters but not too late as to expose the crop to frost.

4.1.2 Moisture

A yield of around 3 tons per hectare requires between 350 to 450 mm of rain per year (Farmer's Weekly, 2018). This equates to 10 to 16kg of maize per millimetre of water and a total of 250 litres of water per plant over a season (Du Plessis, 2013). The relationship between precipitation and yield is, however, non-linear as yield increases with precipitation up to a threshold where yield will decrease (Nxumalo, 2015). This threshold is dependent on the soil temperature. If the moisture does not allow the soil to maintain the ideal soil temperature of 16 - 18 ^oC, yields will decrease. In suboptimal years, elevated levels of CO_2 would benefit maize production because the impact of eCO_2 is the equivalent of additional rainfall.

4.2 Maize Production in South Africa

According to the South African Maize Forum (2020), maize is the most important crop grown in the country. Not only does maize form part of the staple food for most of the population but the maize industry also has a strong connection throughout the South African economy. Mathews (2018) believes South Africa produces maize for three reasons: profit, climate and food.

Firstly, to produce maize it must be economically viable. If it is not viable then producing the crop is not sustainable. The production of maize in South Africa is, fortunately, profitable with an estimated 9000 producers across the country (South African Maize Forum, 2020). Seventy-five percent of the maize produced in South Africa is consumed by the local market (Mathews, 2018). Around 4.1 million tons is used for human consumption, 3.9 million tons for animal feed and the manufacturing industries consume, on average, 650 000 tons per year. Approximately 1.8 million tons is then exported (South African Maize Forum, 2020).

Secondly, the climate of South Africa is suitable for the production of the crop with high lying provinces of the Free State, Mpumalanga and the North West Province being the largest contributors of maize in South Africa contributing, on average, 39.8%, 23% and 18.1% respectively (GrainSA, 2020).

Tables 4.1 and 4.2 show the percentage and total contributions of each province to maize production in the country. The tables reveal that the contribution of these three provinces are considerably more than any of the other provinces. The lower altitude provinces of the Western and Eastern Cape contribute less than 1% each to maize production in the country despite both provinces having strong agricultural sectors.

Table 4.1: Percentage contribution of total maize production by each province (GrainSA, 2020).

% of Total Maize Production											
	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	Average
Western Cape	0,1%	0,1%	0,2%	0,3%	0,2%	0,4%	0,6%	0,1%	0,3%	0,3%	0,3%
Northern Cape	4,8%	5,2%	5,1%	5,7%	4,7%	6,8%	9,1%	4,2%	5,4%	6,0%	5,7%
Free State	39,6%	39,1%	39,8%	41,4%	43,8%	39,6%	28,5%	43,8%	42,2%	40,4%	39,8%
Eastern Cape	0,6%	0,7%	0,8%	0,9%	0,8%	1,0%	1,0%	0,6%	0,7%	0,8%	0,8%
Kwa-Zulu Natal	4,1%	4,3%	4,2%	5,1%	3,9%	5,1%	6,7%	4,4%	5,3%	5,9%	4,9%
Mpumalanga	21,4%	21,1%	20,9%	25,4%	19,5%	24,4%	29,8%	20,5%	22,5%	24,6%	23,0%
Limpopo	1,6%	1,7%	2,3%	2,5%	2,2%	2,8%	4,0%	2,9%	1,9%	1,8%	2,4%
Gauteng	5,3%	5,2%	4,8%	5,1%	4,6%	4,9%	5,7%	4,8%	5,0%	5,4%	5,1%
North West	22,4%	22,5%	22,0%	13,7%	20,3%	15,0%	14,7%	18,7%	16,8%	14,8%	18,1%

Table 4.2: Contribution of each province to the total production of maize in South Africa (Data from GrainSA, 2020)

Total Production of maize in South Africa ('000 t)										
	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018 /19
Western Cape	17.5	14.4	30	33	33.0	38.3	45.0	22.0	33.8	34.2
Northern Cape	609	538.2	617.4	675.3	663.7	679.0	710.0	703.2	669.3	670.2
Free State	5076	4051.5	4823	4884.8	6247.3	3945.0	2213.5	7330.5	5275.0	4543.0
Eastern Cape	80.5	68.1	92.5	108.2	111.4	99.6	76.0	97.3	93.2	92.2
Kwazulu-Natal	524	449.5	512	599	559.1	507.5	522.0	735.0	660.0	669.6
Mpumalanga	2745	2190	2529	3005	2782.2	2429.3	2319.0	3431.0	2817.0	2774.8
Limpopo	210	173	273.5	292	307.0	280.8	310.0	492.0	231.7	200.2
Gauteng	685	542.8	578.5	600	648.4	486.1	442.0	798.0	631.5	607.2
North West	2868	2332.5	2664.5	1613	2898.0	1490.0	1141.0	3135.0	2098.6	1666.5
Total	**12815**	**10360**	**12120.4**	**11810.3**	**14250.0**	**9955.5**	**7778.5**	**16744.0**	**12510.0**	**11257.9**

4.2.1 Free State Province

The Free State has quite comfortably been the biggest producer of maize over the past 10 seasons. Other than in 2015/16 where the province experienced a severe drought resulting in Mpumalanga briefly holding the mantle as the country’s biggest producer, the Free State has asserted its dominance in the production of maize in South Africa. The province lies at well over 1000m (+- 1300m) above sea level and experiences a warm and dry climate. Summer temperatures range between 15 ^{o}C and 32 ^{o}C averaging around 23 ^{o}C (SAWS, 2020). Average rainfall for the province is around 500-600 mm a year but this varies greatly across the province and can range from 300-900 mm a year depending on the region (SAWS, 2020). Although the topography of the province is relatively flat, the Free State has three different climate zones under the Koppen Climate Classification. The two main zones are a semi-arid north western region, where most of the maize is grown in the province, and a subtropical climate in the south-east (Climate-Data.org, 2020). Since the 2009/10 season, the Free State has produced an average of 4 838 960 tons per year (GrainSA, 2020). In 2016 when South Africa achieved its highest maize yield in history, the Free State produced close to half of the maize in the country at nearly 44%.

4.2.2 Mpumalanga

Like the Free State, Mpumalanga is high lying, ranging from 2300m to 1700m above sea level. The average temperature in the summer months is around 26 °C (SAWS, 2020). The province experiences good summer rainfall between the months of September and March averaging around 600mm per year (SAWS, 2020). Since the 2009/10 season, Mpumalanga has averaged 2 702 230 tons of maize per year. Despite this being almost half of the average production of the Free State ,it is still, on average, 473 940 tons more per year than the Western Cape, Eastern Cape, Limpopo, Kwa-Zulu Natal, Northern Cape and Gauteng combined (GrainSA, 2020). Similarly, to the Free State, Mpumalanga experiences two different climatic zones, a high-lying grassveld region experiencing a hot semi-arid climate and a lowveld subtropical humid oceanic climate (Climate-Data.org, 2020).

4.2.3 North West

The North West Province borders the Free State in the region where maize production is the predominant source of income in the agricultural industry. The province experiences summer temperatures that range between 22 °C and 34 °C (SAWS, 2020). Similarly, to the Free State and Mpumalanga the province experiences summer rainfall ranging between 300mm in the northern regions and 700mm per year in the southern regions (SAWS, 2020). The province is dominated by a hot semi-arid climate that borders the north western region of maize production from the Free State. On average, the North West Province has produced 2 190 710 tons of maize in the past ten years which is almost the same amount of the other six provinces combined.

The tables, therefore, show that the Free State, Mpumalanga and the North West province make up the significant portion of the market for maize in the country. The common factor between the three provinces is the hot semi-arid climate with an altitude at above 1000m above sea level. Additionally, the climate of the three provinces all meet the climatic requirements laid out by Du Plessis (2003). All three provinces average close to 500mm of rainfall per annum and average temperatures over 23 °C. It is, therefore, not a surprise that most of the maize in the country is consistently produced by these provinces. The tables above show that the climate of the highveld of South Africa is more conducive to maize production than the low-lying coastal provinces. In fact, the data from GrainSA reveals that since 1990, the Free State, Mpumalanga and the North West province have been the biggest producers of maize without fail. As a result, one can comfortably conclude that these areas experience a climate and soil composition that is more suited to the production of maize.

The final reason maize is produced in South Africa is for food. Maize forms part of many of the food types. The production of meat, eggs and dairy, for example, would be impossible without maize (JW Produce, 2017). In developed countries, maize is generally consumed in produce in which maize is just a contributing factor as feed for animals allowing the consumer to purchase meat, eggs or dairy products (Du Plessis, 2003). However, in South Africa, being a developing country, maize is generally consumed directly and is a staple food source to a large portion of the population.

However, with the threat posed by climate change to the maize industry, South Africa risks losing its maize production if the climate in the Free State, Mpumalanga and North West becomes too hostile for maize production. The three provinces produce, on average, 80.9% of the country's maize which amounts to 9 731 900 tons per year. In a developing country, where maize forms a staple part of most of the population's diet, the sustainability of the industry is incredibly important.

The demand for maize in South Africa is so high that if these three provinces cannot meet the demand then the country would have to make up the shortfall with imports (Mathews, 2018). This is not only an additional cost to the country but there is also loss in income that we normally receive through the 1.8 million tons that is exported, on average. Thus, mitigating the profit reason for South Africa producing maize.

4.3 Established Practices

4.3.1 Tillage

Soil tillage is the biggest factor in affecting the cost of production and is also the foundation of any production of maize and one of the biggest adaptation techniques used in mitigating the effects of climate change (Du Plessis, 2003). Soil tillage prepares the soil structure for production and most optimise the infiltration of water into the soil whilst minimising the evaporation (Farmer's Weekly, 2018). It is also one of the biggest factors considered regarding CO_2 emissions into the atmosphere and, thus, contributing to climate change.

4.3.1.1 Zero till

Zero tillage forms part of conservation agriculture which is used in order to try to produce the maximum amount of output with the lowest possible input (Precision Agriculture, 2020). Additionally, a report released by advisory firm, ICF International, revealed that no till farming leads the way in reducing the emissions of greenhouse gases and reversing the harmful effects of climate change (Barrera, 2016). The premise of zero tillage farming is simple: never use a plough when preparing the soil for planting. The soil is therefore left undisturbed and as natural as possible (Du Plessis, 2003). Du Plessis (2013) continues by stating that the prerequisite is that there is at least 30% of soil must be covered by plant matter to reduce the risk of erosion. Barrera (2016) predicted that by 2020 more than 30 million metric tons of greenhouse gas emissions would have been prevented had all farmers adopted no till practices. This would have a considerable impact on climate change and ultimately, on the production of maize around the world. Zero tillage is the polar opposite tillage method to conventional tillage and there have been several studies concluding that zero tillage results in similar, and in some cases, better yields than conventional tillage (Subbulakshmi, et al. 2009). However, there have been studies that have found that in some cases zero tillage produces much lower yields than conventional tillage so the debate between the two methods has not been concluded.

4.3.1.2 Mulching

Mulching also forms part of conservational tillage but is not as drastic a change from conventional tillage as zero tillage. Mulching does disturb the soil, however, it is done without destroying crop residue left on the surface of the soil (Precision Agriculture, 2020). According to Subbulakshmi et al. (2009), the higher residue left in the soil results in there being a much higher soil organic content. Allowing for a naturally gradual increase in the organic content in the soil and could, in the long run, save farmers on their costs of fertilisation, as a result their costs of production will be lower. However, there is not enough evidence yet to conclude whether this saving in fertilisation costs can offset the potential loss in yields. Much like the zero-tillage vs conventional tillage debate, studies are not conclusive on their yield potential.

4.3.1.3 Reduced tillage

Reduced tillage is the third established practice which forms part of conservation agriculture. It involves reducing the disturbance of the soil, reducing the emissions of greenhouse gases whilst simultaneously cutting down on costs of production. It is, somewhat, the happymedium between zero tillage and conventional tillage. By adopting this method, nutrient turnover in the soil is slowed and the development of a more stable environment is encouraged by decreasing the intensity at which the soil is tilled (Rusch et al, 2010). Dependingon the preceding crop, the soil type and the residue management, tillage is needed to preparea seed bed for planting (Subbulakshmi et al, 2009). Reduced tillage allows for the farmer to prepare the seed bed to plant but at a much lower intensity to conventional tillage allowing for some of the cost saving that zero tillage affords as well as the weed control of conventional tillage. Subbalakshmi et al. (2009) do warn that, much like the other two conservational tillage methods, studies have not yet been able to prove that the yields using these methods are sufficient to justify using them over conventional tillage. They do, however, result in lowerCO^2 emissions which, in the future, could potentially impact the production of maize.

4.3.1.4 Conventional tillage

It is widely recognised that conventional tillage is not sustainable when one considers the current patterns of climate change (Okese, 2016). However, it is important to note that for any of the conservational tillage methods mentioned above, there needs to be a certain level of crop residue from the previous season for those methods to be worthwhile. Therefore, in areas where yields are low, conventional tillage is the best practice to optimise output.

Conventional tillage is, as the name suggests, the method of tillage that most people recognise as “conventional”. It involves working the soil by ploughing and preparing a seed bed that is clear of any other plant material before the crop is planted. Conventional tillage buries weeds and any emerging seeds as well as exposing the underground parts of weeds which causes them to die (Subbulakshmi et al. 2009). It is, therefore, a highly effective method in controlling perennial weeds in the soil. Unfortunately, due to the high input costs involved with the method, farmers using conventional tillage tend to have much higher costs of production in comparison to those that use some of the conservational tillage methods.

4.3.2 Planting Dates

Planting dates vary from region to region as planting can commence as soon as the soil moisture and temperature are suitable for germination (Du Plessis, 2003). In the Free State, planting usually commences in November and if temperatures reach a minimum of 10 ^{o}C to 15 ^{o}C for seven days, germination should occur normally. According to Phillips (2019), soil temperature during the planting of the crop is the most critical environmental factor that influences germination and the eventual emergence of the plant. Phillips (2019), therefore, believes that a minimum soil temperature of 14 ^{o}C should be used as the general rule. The reason for this is because the most common ancestor of modern hybrid maize originates from Mexico which experiences a warm climate.

However, maize is also susceptible to temperature shocks when planted into dry soil. During the interviews conducted for this research paper, many of the participants pointed out that dry soil, naturally, is warmer than soil with sufficient moisture. However, because rainfall, on average, has been falling much later into the season, farmers are having to plant their crops much later than they would prefer.

Additionally, due to many farmers shifting their planting methods towards zero or reduced tillage, the increased soil moisture content has resulted in their soil being cooler than the optimum temperature during planting.

Long et al. (2017) found that planting dates are significant to the overall yield of the crop. According to Long et al. (2017) there is a significant correlation between the planting dates and the latitude of the region. The study concluded that planting dates become more significant the later one plants and results in high latitude countries like South Africa having much smaller planting windows than countries closer to the equator.

Evidence of the significance of planting dates on yield can be found in the latest maize season. Estimates for the 2020/21 marketing season (maize grown and harvested in 2020) suggest that there will be a decrease in the production of maize (Venter, 2020). In the Free State, rain was exceptionally late in most of the province and in some areas, exceptionally early. Only 20% of the total maize was planted within the optimal planting window (Venter, 2020).

4.3.3 Plant populations

Results of studies looking into the impact that plant densities have on overall yield is inconsistent. However, most studies assume that lack of moisture is the reason most producers of grain crops are reluctant to increase their plant populations (de Oliveira Silva et al. 2020). According to Du Plessis (2003), plant populations are affected by the two biggest factors of maize production: water and temperature. The Free State Province, dryland maize yielding around 2 tons per hectare will require a plant population of around 14 000 plants per hectare. On average, yields of 6 tons per hectare require around 28 000 plants per hectare. However, in seasons where conditions are more suitable or when there is irrigation available, farmers can afford to increase their plant populations.

4.4 Previous Studies

In a world where global surface temperatures are increasing and the frequency and intensity of drought has increased, different variations have been used to measure the economic impact of climate change on a number of crops.

Mqadi (2005) gave evidence of findings made by Deressa (2003) using a Ricardian model approach adopted to analyse sugarcane farmer adaptations to environmental factors due to climate change. Sugarcane is also a C4 plant so it was expected that the results should reflect, or, at least, be like that of maize. The study by Deressa (2003) found that sugarcane is more sensitive to increases in temperature in the future than changes in precipitation as direct consequences of climate change. Following this result of precipitation not having as big an influence on production, Deressa (2003) also found that in the typical sugarcane production, irrigation did not significantly reduce the harmful impacts of climate change. Therefore, farmers in the region have had to rely on other adaptation techniques to manage the warmer conditions and still benefit from the improved WUE.

Gbetibouo and Hassan (2005) found similar results in their study on the South African field crops of maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean. Again, marginal changes in temperature rather than precipitation had a more significant impact on the plants. On average, temperature increases were found to have a positive impact, and a reduction in rainfall had a negative impact (albeit a smaller impact than the change in temperature). Benhin (2006) argued that, on average, the increase in temperature only improves yield in the cooler seasons (winter, autumn and in some scenarios, spring) but reduces yield in the summer. The findings by Gbetibouo and Hassan (2005) and Benhin (2006) indicate the importance of location and season on the means in which farmers deal with the challenge of climate change. Therefore, adaptations to climate change cannot be uniform across the country (Gbetibouo and Hassan, 2005: 150). As a result, the findings in the study by Deressa (2003) that irrigation is not statistically significant can be isolated to the region of that study.

Nxumalo (2015) confirms that different regions need to be treated separately due to the minor changes in the effectiveness of certain adaptations. However, although plants are more sensitive to changes in temperature than precipitation, irrigation is still statistically significant. Irrigation is not only important to crop growth, as CO_2 fertilisation assists in the growth of the plant, but also on grain quality. The literature review referred to concerns brought to light by Myers et al. (2014), who believes that although CO_2 fertilisation is beneficial to the plant growing, grain is believed to have reduced quality. According to Myers et al. (2014), grain has been found to have lower levels of certain nutrients such as zinc, iron and in some cultivars, protein. Irrigation is, therefore, beneficial to yield and to crop quality (Nxumalo, 2015).

Additionally, according to Nxumalo (2015), hybrid seeds and land size are also statistically significant. Farmers using hybrid seeds and a dryland cropping system have had a positive impact on their yields and with increases in land size come further increases in net revenue. Hybrid seeds generally also showed higher revenues in the study by Sibanda et al. (2016). Farmers studied by Sibanda et al. (2016) using hybrid seeds as well as additional management levels performed better than those using common maize varieties and no adaptations.

According to Benhin (2006), changes in the timing of rain within a season due to climate change is also statistically significant. This has forced farmers to adjust their planting and harvesting dates. Early summer rain is more beneficial but, the later in the summer the rain falls, the bigger the impact of the warmer temperatures are and as a result, lower yields are achieved.

Mulungu and Ng'ombe (2019), emphasize the importance of adaptation to the changes in the climate. Literature shows the negative impact that climate change is having on maize production and without proper adaptation strategies these negative impacts are sure to increase into the future.

Mulungu and Ng'ombe (2019) suggest more competent irrigation technologies to those who have the water available. This aligns with the findings of Nxumalo (2015), Sibanda et al (2016) and Myers et al. (2014), who concluded that irrigation is statistically significant to the production of maize. Additionally, literature suggests the continued research and development of hybrid maize (Mulungu and Ng'ombe, 2019; Nxumalo, 2015; Sibanda et al. 2016). Being able to adapt to the changing climate includes using the most suitable variation of drought tolerant hybrid maize to the specific region and climate is paramount to the future of maize (Gbetibouo and Hassan, 2005). Lastly, being able to apply "climate-smart" adaptation techniques is essential for the sustainability of production (Mulungu and Ng'ombe, 2019). The importance of understanding the impact that human activities have on climate change and ecosystems can have a huge influence on the future of agriculture. Literature strongly encourages the reconsideration of human activities on ecosystems, not only through reducing emissions of CO_2, but also in maintaining the environment in which we produce crops.

4.5 Rhodes University CO_2 Fertilisation Experiments

Simulation experiments were conducted at the Rhodes University Elevated CO_2 Facility (RUECF) as part of Tebdis Bobape's MSc under the supervision of Professor Bradford Ripley. The experiments were conducted in conjunction with GrainSA as part of their eCO_2 project which looks at the response of maize to drought under future CO_2 atmospheric levels (GrainSA, 2020).

The experiment made use of Open-Top Chambers (OTCs). The OTCs allowed for the levels of CO_2 as well as the amount of water available to the plants to be controlled. Additionally, the OTCs were covered in sheeting that transmitted 94% of radiation, each chamber was ventilated and airspeed was controlled to ensure that the difference between the ambient temperature and the temperature of the chamber was within 4% (Ripley, et al. 2020).

Six cultivars were grown under two targets of CO_2 concentration (400ppm and 800ppm). The 400 ppm being the ambient concentration level of CO_2 and 800ppm being the elevated concentration level expected by the turn of the century (Tubiello, et al. 2000: 179). Under the two levels of CO_2 concentration, cultivars were subject to either drought conditions (deliberately not watered with the only water available to the plant being through the rainfall at the site) or were well-watered.

The experiment included the different watering regimens in their study because of the results of previous studies which looked at the response of C4 plants to eCO_2. Some of these studies are included in Chapter 2 which reviewed how increasing concentration levels of CO_2 can have significant effects on grain production. The chapter discussed previous research that compared C3 and C4 plants and found that C4 plants have very small responses to eCO_2 as compared to C3 plants (Markelz, et al. 2011, Jin et al., 2017, Leakey et al., 2006, Beery, 2012). The response of C4 plants is different, it is a reduced stomatal conductance under eCO_2 resulting in an indirect effect of an improved water use efficiency (WUE). Therefore, the response of eCO_2 on maize is most evident when drought is considered in the experiment.

The six cultivars all produced significantly different levels of biomass and were affected by the different treatments that they were subject to. However, all the cultivars responded in a similar manner to the drought conditions and the eCO_2. Therefore, the cultivars were pooled, allowing for the effects of treatments to be analysed. Through pooling the cultivars, the treatments proved to be significant in their impact on the plants.

The plants that were subject to drought at 400ppm produced the smallest amount of biomass. Those plants that were watered at the same level of CO_2 concentration as well as those subject to drought at 800ppm produced similar levels of biomass. The biomass produced by these two treatments was roughly 40% more than the plants under drought and ambient CO_2 conditions. However, the greatest amount of biomass was produced by the plants at eCO_2 and well-watered. The biomass of these plants was, on average, 77% more than the biomass of the ambient and drought treated plants. This allowed for the study to conclude that eCO_2 completely mitigated the effects of drought at the ambient CO_2 concentration. The results of the biomass responses were similar when the cultivars were grouped by grain colour (white vs yellow) and by region (east vs west).

In addition to the biomass responses of the plants to the different treatments, the photosynthetic rate as well as the stomatal conductance (which will impact the soil water content) are of interest. The simulating experiments found that they both declined as drought increased and their responses, much like the response of biomass, was not different under different cultivars. Therefore, cultivar responses could be pooled to allow for a comparison of the different treatments.

Once pooled, the response of the photosynthetic rate was different depending on the treatment the plant was subject to. Plants under 400ppm and drought conditions had a photosynthetic rate that declined the fastest. The rate of decline decreased slightly when exposed to 800ppm under drought conditions. When watered, the photosynthetic rate declined much slower, whether the plant was under ambient or elevated CO_2 concentration. Therefore, the experiment concluded that plants show a decline in their photosynthetic rate even when they are well-watered. However, the rate of decline is much faster under drought conditions and particularly when exposed to ambient levels of CO_2. This rate of decline is slightly reduced by eCO_2.

The soil water content (SWC) between treatments displayed differences due to the impact eCO_2 has on the stomatal conductance of the plants. At 800ppm, the stomatal conductance of plants was much lower than the comparable plants at 400ppm. Therefore, the SWC was higher at eCO_2 than at the ambient level. Interestingly, the difference between the SWC under the two levels of CO_2 levels was bigger when they were well watered. This shows that despite being watered daily, irrigation is not sufficient in offsetting the water loss at the lower CO_2 level.

The plants grown under drought conditions received the exact same amount of water (rainfall on the experiment site). Therefore, the difference between the SWC at 400ppm as compared to 800ppm shows the water saving effect of eCO_2. According to Ripley et al. (2020) there was a potential saving in excess of 3100mm over the course of the experiment. The experiments explained why plants subject to eCO_2 performed well even under drought conditions. The water saving is based on the calculation below:

Volume of water (L) = volume of soil accessed (L) x soil bulk density (kg L^{-1}) x SWC (%/100)

The SWC and bulk density were measured but the volume of soil accessed is an estimate. The experiment assumed:

Volume of soil accessed (L) = Area planted x Rooting depth of 0.5 – 1.5m.

Then the rainfall equivalent can be calculated assuming that this volume falls on the surface area as calculated above.

Assuming a rooting depth of 0.5m the saving is: 1507mm

Assuming a rooting depth of 1m the saving is: 3014mm

Assuming a rooting depth of 1.5m the saving is: 4522mm

However, irrigation and CO_2 fertilisation maintain a SWC of more than 0,15%. SWC less than 0,15% is the approximate value of SWC where there is an exponential decline in potential and soil water becomes inaccessible to plants. Therefore, the offsetting effect that eCO_2 has will not be able to mitigate the effects of severe drought when SWC levels drop below this 0,15% threshold.

4.6 Potential economic impact of eCO_2 on maize production

The difference between the SWC and plant biomass under the two levels of CO_2 concentration discussed in 4.5 can be used to calculate the potential economic impact that eCO_2 has on maize production. Maize yields are higher in seasons where there has been good rainfall or when they are under irrigation. In order to justify introducing irrigation, the increase in the yield of the crop must offset the cost of investing in irrigation as well as the additional costs of production that would come with irrigation (Henggeler and Massey, 1997). The cost of investing in irrigation can, therefore, be assumed to be the economic impact of eCO_2 if concentrations were doubled to 800 ppm. The relationship between maize yield and water availability is where eCO_2 can economically influence maize production.

Considering the findings of the CO_2 fertilisation experiments, the findings of Adee et al. (2016) are particularly interesting. Their study included the effect that the evapotranspiration rate and WUE had on hybrid maize. Their study concluded that in drought stressed environments, where there would normally be a high evapotranspiration rate, drought resistant hybrid maize was able to yield more. However, when the same drought tolerant hybrid maize was subject to a non-stressed environment, where there generally is a low evapotranspiration rate, there was no penalty in the yield potential to a non-drought tolerant variety. Economically, this is significant to the investment in drought tolerant hybrid maize. The drought tolerant hybrid maize makes use of the positive impact of eCO_2 and reduces the evapotranspiration rate improving the WUE efficiency of the plant. However, when the plant is not subject to drought, the investment in the drought tolerant maize is not wasted as the plant suffers no penalty in yield in comparison to the non-drought tolerant variety (Adee, et al. 2016).

The simulating experiments suggested that the effect of eCO_2 completely mitigated the impact of drought. The 40% difference in plant biomass between plants exposed to drought under ambient CO_2 and elevated CO_2 illustrates that the plant capacity is increased by eCO_2. The study also showed that

eCO_2 has the same impact as irrigation on the plant biomass of maize. Therefore, the economic impact of eCO_2 can potentially be calculated by the difference in yields between dryland and irrigated maize.

According to maize trials conducted by Assefa et al. (2012), irrigated maize yields increased at an average rate of 30kg per hectare per year faster than the rate that dryland yields increased over the period of 1939 to 2009. This shows that although yields are increasing overall because of technology and management, irrigated maize yield is increasing faster than dryland maize. Similarly, Henggeler and Massey (1997), found that there was a relative yield increase of 29,5% under irrigation compared to dryland conditions. These studies were, however, conducted in the United States and as Henggeler and Massey (1997) point out, yield increases will vary year by year and according to regions.

The impact of irrigation on the study site relevant for this project can be seen by the results of farmer 5 in chapter 5. In the 2019 production season, the dryland yield for the farm was 2,5 tons per hectare. However, on the same farm and in the same season, there was a production of 10 tons per hectare under irrigation. The last traded price of white maize (the variety planted) in March 2019 was R2 462,00 per ton (GrainSA, 2020). This results in a R18 465 difference in income per hectare, assuming optimal irrigation

Introducing irrigation is therefore an insurance policy, ensuring that yields will be more consistent year on year. Irrigation has the potential to save farmers in disastrous years and take advantage of profitable years. The simulating experiments, however, suggest that this is an insurance policy that, potentially, would not be necessary in the future as the impact of eCO_2 fulfils the same role as irrigation would, provided that SWC does not dip below the 0,15% threshold and that the required adaptation techniques are used.

The most reliable method to determine the production potential, though, is a long-term yield data collected by each individual maize producer (Du Plessis, 2003). Through adopting a long-term comparison of yields it will reflect the yield of the specific environment of the farm subject to the effect of adaptation techniques.

Tables 4.3 and 4.4 show the rainfall data for the two regions in the case study in chapter five.

Table 4.3: Rainfall data of Ladybrand 2010 - 2019

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jan	94.31	63.82	56.36	45.95	41.01	54.65	54.01	59.54	36.78	71.5
Feb	28.62	30.75	45.6	37.37	37.2	20.33	32.18	60.61	26.45	88
Mar	23.17	38.21	47.76	46.37	43.65	25.72	16.73	10.45	50.01	80.9
Apr	26.72	33.37	14.55	15.36	17.49	6.1	26.92	8.85	13.17	163.6
May	14.67	18.75	8.33	1.88	3.79	3.29	6.63	2.37	3.77	22.1
Jun	15.7	43.29	29	0.42	2.74	21.83	3.7	4.09	0	0.9
Jul	0.34	17.93	13.45	2.23	0.05	34.42	2.08	0.57	3.39	2.8
Aug	1.06	1.42	8.1	7.21	19.85	1.9	3.33	0.78	25.11	1.1
Sep	1.16	3.04	21.34	9.18	5.82	13.63	24.11	10.56	5.09	3.3
Oct	50.13	23.68	39.69	20.63	29.42	21.68	30.96	27.66	17.4	2.8
Nov	57.9	21.7	52.98	53.17	97.15	24.5	76.68	16.51	9.3	43.7
Dec	117.86	61.89	83.3	75.25	79.23	24.12	56.34	48.6	64.8	141.5
Total	431.64	357.85	420.46	315.02	377.4	252.17	333.67	250.59	255.27	622.2

Table 4.4: Rainfall data of Viljoenskroon 2010 - 2019

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jan	101.38	52.03	25.54	43.2	21.11	19.26	54.89	50.42	21.62	203.4
Feb	13.6	24.05	28.51	17.02	38.46	6.34	20.69	79.1	44.67	157.6
Mar	47.21	21.77	24.89	27.04	33.69	49.32	15.46	4.9	60.94	48.6
Apr	41.13	28.68	4.97	37.3	1.5	12.01	23.63	12.42	7.83	160.3
May	11.51	9.47	0.17	7.19	1.63	0.29	8.7	0.7	6.98	3
Jun	0.61	8.66	9.56	0.11	1.87	7.22	3.88	0	0	0
Jul	0.62	0.86	0.26	0.11	0	4.4	0.45	0.4	1.36	0
Aug	0	0.3	0.44	0.06	4.16	0	0.38	0.01	1.96	0
Sep	0.4	1.89	22.07	0.78	3.53	4.08	3.67	3.1	0.32	2.9
Oct	19.9	17.54	27.24	18.25	3.85	9.86	31.91	13.39	50.9	11
Nov	41.98	19.93	22.94	39.29	44.64	11.12	83.86	15.41	19.8	148.6
Dec	110.92	49.97	55.57	42.78	52.14	27.34	44.79	33.82	100.7	264.2
Total	389.26	235.15	222.16	233.13	206.58	151.24	292.31	213.67	317.08	999.6

The tables show the inconsistency of rainfall for the 2 regions and the drought conditions that they have been experiencing. Despite the extremely low rainfall, especially in the western region of Viljoenskroon, the Free State has still managed to produce a higher level of output than the other provinces. The water saving effect of increased CO_2 could potentially have a large economic impact as the concentration levels increase, especially in years where rainfall is low, which as the tables show is a reality that the two regions are facing.

As mentioned in section 4.5, the experiments found that the water saving effect at the elevated level of CO_2 of 800ppm is the equivalent of an additional 1507 - 4522mm of rainfall per year. This is much higher than the long-term average rainfall for the Free State province. Tables 4.3 and 4.4 show that in the last 10 years, each focus region only received higher than the average once, in 2019. The results of the experiments are therefore significantly higher than the rainfall of the study area.

According to Du Plessis (2013), each millimetre of rain equates to 10 to 16kg of maize per hectare in a season. The water saving effect of eCO_2 is therefore the equivalent of an additional 10.5 to 16.9 tonnes per hectare (using 0.5m rooting assumption) or an additional 45.2 to 72.3 tonnes per hectare (using the 1.5m rooting assumption) of maize in a season. Using the same maize price of R2 462,00 per ton (GrainSA, 2020) that was used earlier, the water saving effect results in a potential range of additional income of R25 851 to R178 002 per hectare (at 800 ppm which is predicted for 2100).

This, however, is a much higher concentration level of the gas than the current levels of CO_2. Results assume that there is a linear relationship between the water saving effect that accompanies the rise in CO_2 levels and an increase in yield. Conversely, Nxumalo (2015) and Sibanda (2016) state that there is not a linear relationship between yield and water availability. There is a threshold where increases in water start to deplete the yields. These increases in additional water resulting in the significantly large increases in yields and income are unrealistic.

However, assuming a sliding scale of water saving and CO_2 concentration levels in the atmosphere it is possible to estimate the year to year changes. For every 1 ppm increase in CO_2 in the atmosphere there is a water saving equivalent of 1.88 to 5.65mm of rain. According to Lindsey (2020), 2019 reached a record high CO_2 concentration level of 409.8 ppm. This is a 2.5 ppm increase from 2018 which is the same increase from 2017 to 2018.

Assuming that there is a consistent 2.5 ppm increase every year, there will be a water saving equivalent of 4.7 to 14.125mm of additional rain, or 47 to 226 kg higher yield per hectare, depending on the rooting depth, each year until the threshold of the linear relationship between water and yield is reached. This will result in an additional R115 to R556 increase in income per hectare year to year.

4.7 Conclusion

The chapter highlights the importance of maize in South Africa. The crop has an influence on the sustainability of the economy and for food security. However, climate change creates a challenge to the longevity of the crop particularly because most of the maize produced in the country is only grown in three of the provinces. The country is extremely reliant on the highveld region to produce enough maize to meet the demand of the country as well as for exporting. The threat posed by climate change is that whilst currently the climate of the Free State, Mpumalanga and the North West is ideal for the production of the crop, if current emissions of CO_2 continue and the rate at which the climate is changing, these areas could potentially be less suitable for maize production.

Adapting to the changing climate is, as a result, vital to the sustainability of production for these provinces. The chapter delved into some of the established practices of maize production and briefly discussed some of the adaptation options available within these practices. Adopting a different approach to soil tillage is one of the methods that the chapter identifies which can be adapted. The chapter compared the conservation tillage approaches of zero tillage (where the soil is not tilled), reduced tillage (where soil is subject to soil tillage less frequently) and mulching (where plant residue is left on the surface of the soil after tillage) to the conventional approach of soil tillage. Furthermore, planting dates and the plant populations add an additional challenge to the management strategy for ideal production.

Previous studies into the impact of climate change on other C4 crops and maize identified that irrigation, hybrid seeds and land size are statistically significant to the sustainability of production. Additionally, the effect of an increase in global surface temperature was identified as more damaging to future maize production than the decrease of precipitation. The effect of C4 plants coping with less precipitation was confirmed by the simulation experiments conducted by the Rhodes University Botany Department.

The simulating experiments found that under elevated levels of CO_2 the effect of drought was completely offset by the positive effects of an improved WUE and lower evapotranspiration rate that accompany the higher levels of the gas available to the plant. The results of the experiment found that at their elevated CO_2 level, 800ppm, between 1507 and 4522mm of water was saved. Using these findings, the study was able to adjust the figures to current increases and found that the water saving effect of elevated CO_2 resulted in and additional R115 to R556 increase in income per hectare per year.

Economically, this is important as the improved WUE by the plants subjected to elevated CO_2 can, according to the simulating experiments, offset the need for irrigation in the future. The literature further boosts the future of maize production by the findings that hybrid drought tolerant maize does not perform any differently to non-drought tolerant maize in years where the plants receive adequate water.

Therefore, climate change in the form of elevated levels of CO_2, increases in temperature changes and precipitation patterns, do have varying economic impacts on maize production. This is particularly worrying for South Africa as the country produces 80,9% of its maize in three provinces which experience the ideal climate for the crop. Climatic changes in these provinces could spell disaster for the maize production of the country. However, it is possible to overcome the challenges posed by the changing climate by making use of the positive effect of the water saving found by the simulation experiments, provided one can adapt. The crux of the economic impact of climate change is the ability to adapt. Chapter 5 explores the production and adaptation in the country's largest maize producing province, the Free State.

CHAPTER FIVE

Analysis of Survey

5.0 Introduction

The purpose of the case study was to compare the results obtained by the Rhodes University Botany Department in their simulation experiments (Chapter 4) and the literature to the experiences of maize farmers, through a practical review on the production of maize in the province. The study aimed to ascertain whether the results of the impact of elevated CO_2 were replicated in the maize industry and to estimate the economic costs that maize farmers are facing as a result. Ten commercial maize farmers were approached and were asked to complete a questionnaire and interview. Of interest were the farmer's adaptation techniques, their costs of production and their returns.

The chapter explores the study site, its agriculture and climate, the findings of the questionnaire and interviews are revealed, and a conclusion is drawn from the findings.

5.1 Study Site

The study was conducted in the Free State Province of South Africa, which is the third largest province of the country. The province makes up just over 10% of South Africa's area (Davis et al, 2006). On average, over 35% of South African maize is produced in the Free State (Moeletsi et al., 2016). According to Greyling and Pardey (2018), the Free State produced 38.8% of South Africa's total commercial maize output on 42.7% of the planted land in the country in 2015. More recent figures released by GrainSA (2020) suggest that the provinces' contribution over the last ten planting seasons is closer to 40% of the country's production.

In addition to the province producing the most maize in the country, the Free State also produces large amounts of other grain products included in table 5.1. The large climate differences within the province allows for there to be a wide variety of crops grown throughout the province. Livestock is also a prominent produce from the province and, according to Scholtz (2018), nearly all the country's cherry and asparagus production comes from the eastern Free State.

Table 5.1: Crops grown and their seasons in the Free State province (Adapted from JECAM, 2020)

Crop	Type	Season
Sunflower	Early	November - January
Sunflower	Normal	January - March
Soya beans	Normal	November - February
Groundnuts	Normal	December - March
Sorghum	Normal	November - March
Pasture	Normal	September - March
Wheat	Normal	July - December
Forage	Normal	May - September
Alfalfa	Normal	January - December
Oats	Normal	July - December

5.1.1 Climate

Chapter 4 reported that the province is mostly semi-arid with the eastern parts of the province experiencing a more humid subtropical climate and the western half of the province a semi-arid climate according to the Köppen climate classification (Moeletsi, et al. 2011). When looking at the topography of the province it makes sense that there is a difference in climate between the regions with the west being made up of plains and the east being mountainous as it borders the Drakensberg and Lesotho mountain ranges (Moeletsi et al, 2010).

5.1.1.1 Temperature

The province experiences warm to hot summers and cool to cold winters. Areas in the east experience frequent snowfall in the winter months and the west can be extremely hot, particularly in the month referred to as stress month by farmers, January (JECAM,2020).

Temperature data was studied for two towns which were most central to the farmers interviewed in each of the regions. For the west, Viljoenskroon was looked at, and Ladybrand was selected for the east. Temperature data is from Climate-Data.org.

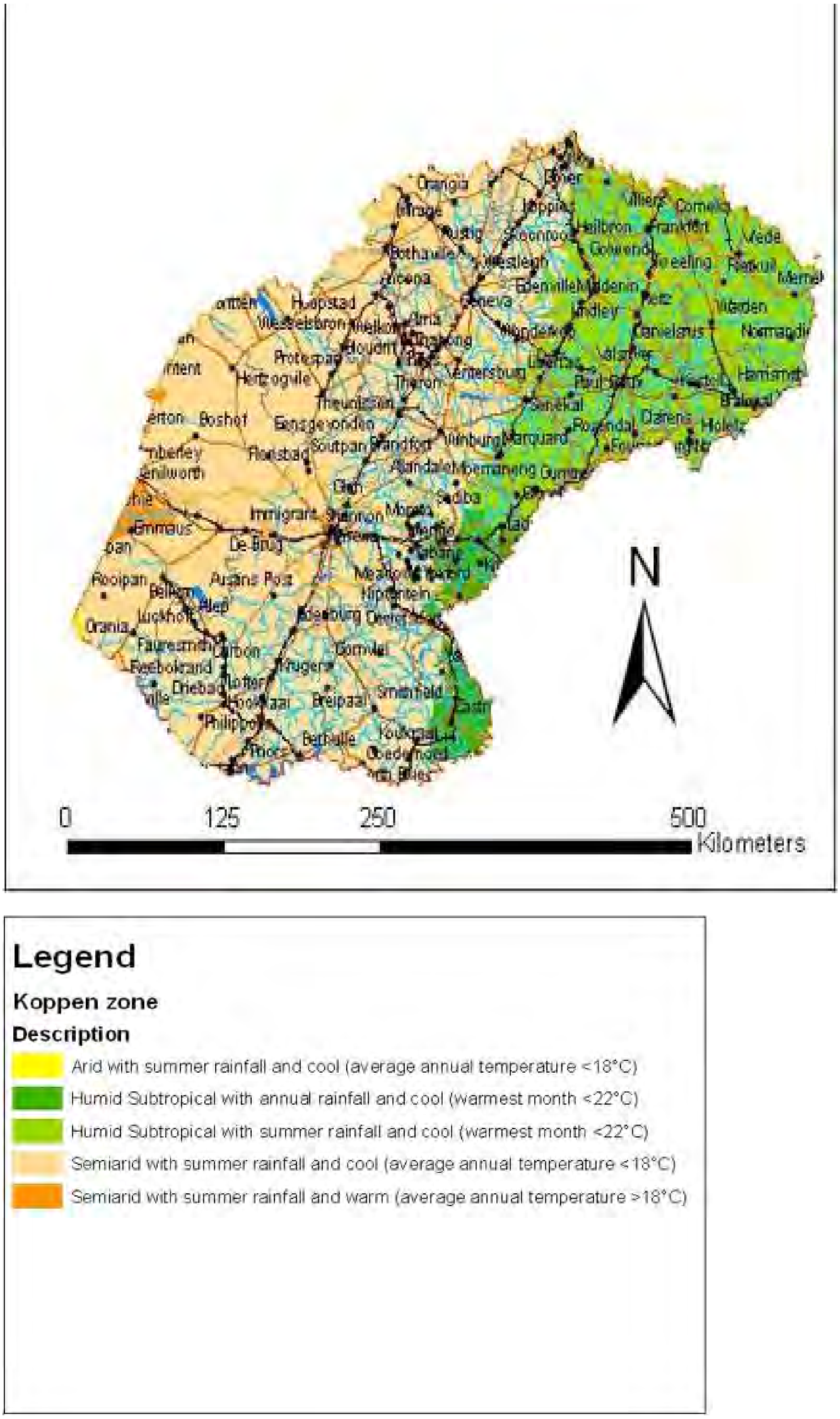

Figure 5.1: Koppen Climate Classification of the Free State Province, South Africa (JECAM, 2020)

Viljoenskroon has an annual average temperature of 16.7 °C. January is the region's warmest month averaging 22.4 °C and July being the region's coldest month averaging only 7.6 °C. During the maize season (November to March) average temperatures range between 20.1 °C and 22.4 °C. The region does, however, frequently experience days with temperature in excess of 30 °C over this time. For example, December in Viljoenskroon averages 27 days with a maximum temperature of 30 °C or more in the month.

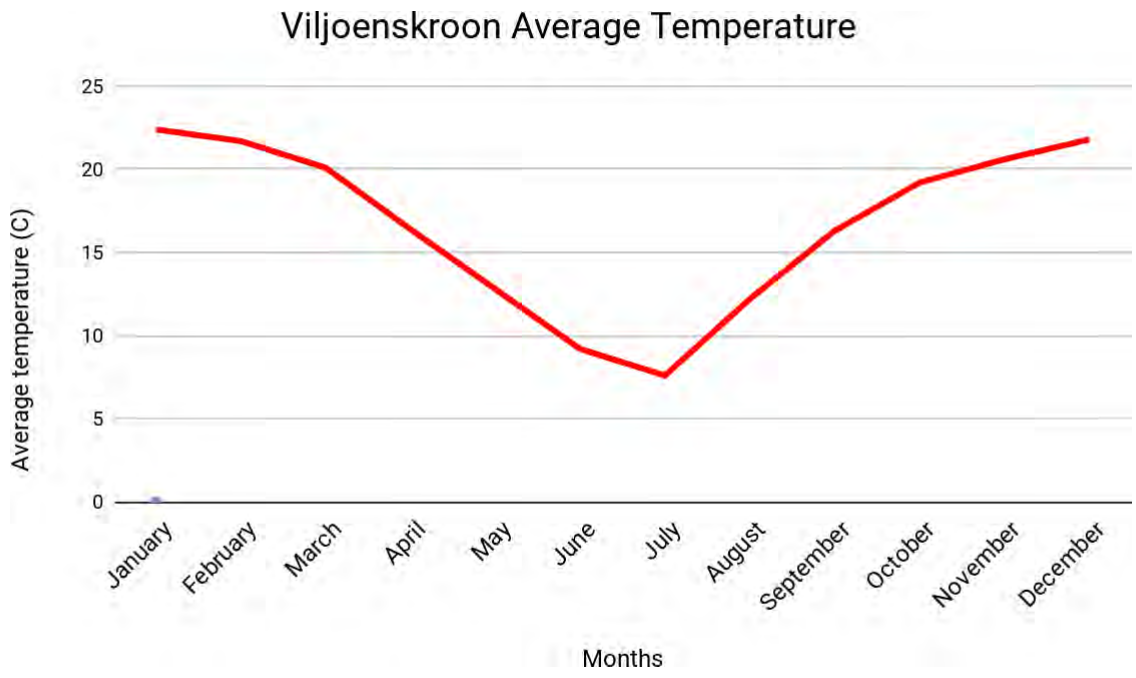

Figure 5.2: Average temperature of Viljoenskroon (Figures from Climate-Data.org)

Ladybrand, on the other hand, has a slightly cooler climate to Viljoenskroon with an annual average temperature of 14.8 °C. Like Viljoenskroon, January is the hottest month of the year averaging 20.6 °C. June and July are normally the coldest months of the year for the region at 7.6 °C. The maize season temperatures range from 18.1 °C to 20.6 °C. Although average temperatures are lower for the region in comparison to Viljoenskroon, the region is experiencing more frequent days in excess of 30 °C.

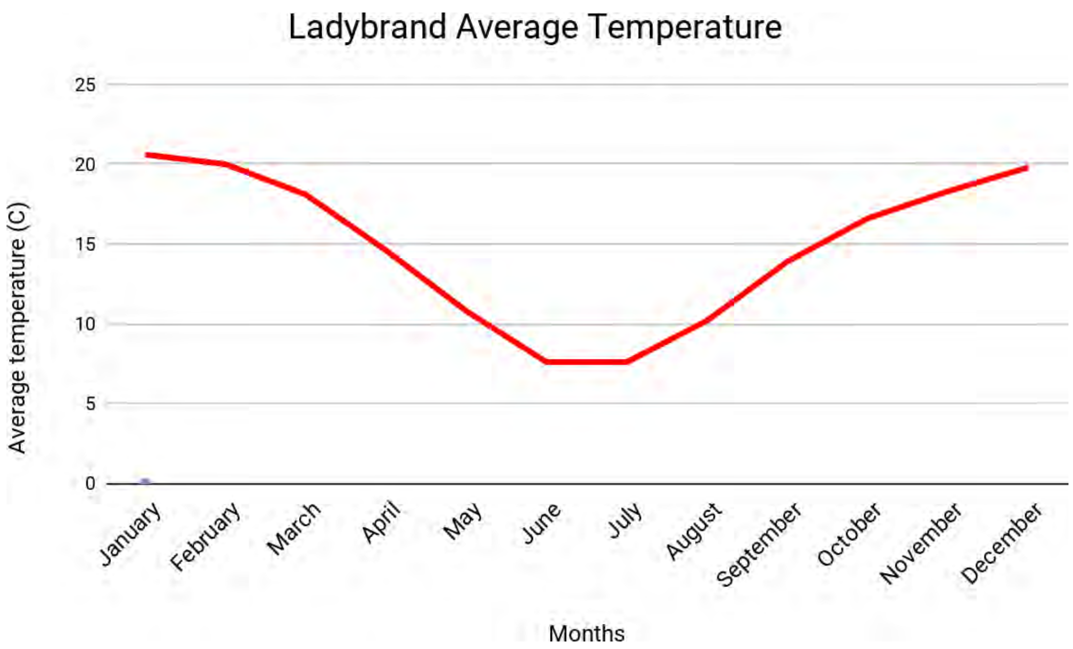

Figure 5.3*: Average temperatures of Ladybrand (Figures from Climate-Data.org)*

5.1.1.2 Precipitation

The precipitation of Viljoenskroon and Ladybrand were also studied and as expected, the eastern region of Ladybrand received higher rainfall than the western region of Viljoenskroon (Climate-Data.org).

Average rainfall for Viljoenskroon is 609mm for the year. However, according to the farmers interviewed, the records for their farms are slightly lower. As well as being the hottest month of the year, January is also, on average, the wettest month of the year with average rainfall for the month being 104mm. July is the driest month of the year, averaging only 7mm of rain on average.

Rainfall for the Ladybrand region is about 696mm per year on average. January and February average over 100mm per year (109mm and 101mm respectively). July is also the driest month in Ladybrand averaging only 12mm per year.

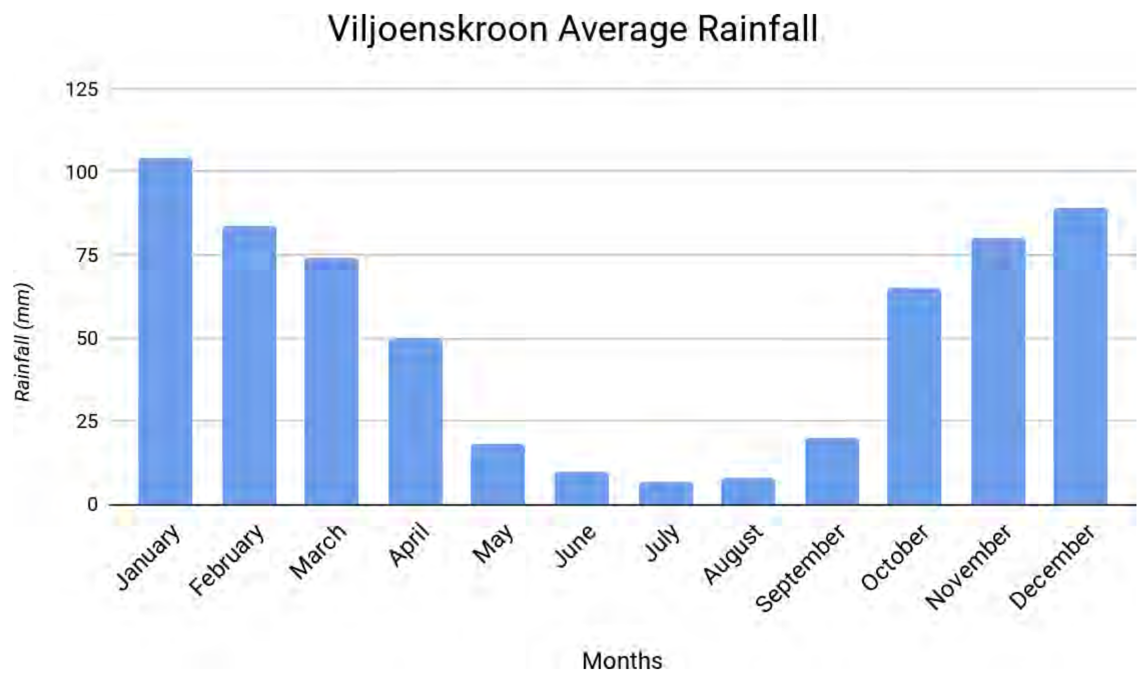

Figure 5.4: Average rainfall of Viljoenskroon (Figures from Climate-Data.org)

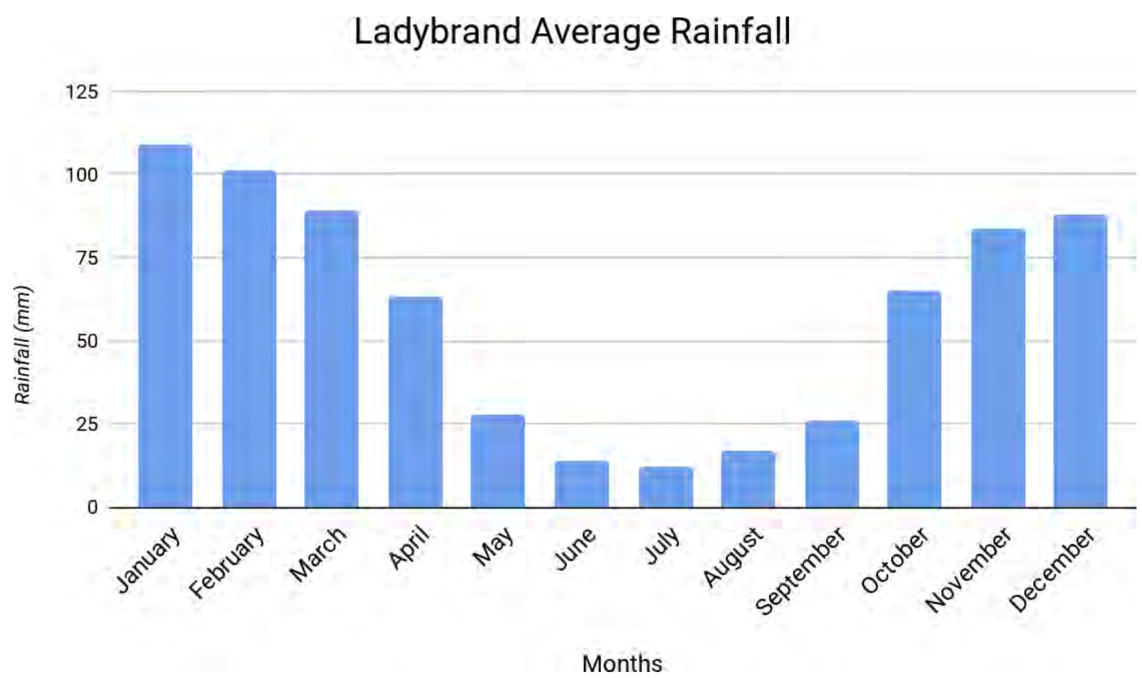

Figure 5.5*: Average rainfall of Ladybrand (Figures from Climate-Data.org)*

5.2 Questionnaire response

The case study compared the western to the eastern production region. There were two reasons for this. Firstly, the climate between the two regions is different as already discussed in 5.1. Secondly there is a recognised separation between the eastern and western production regions by seed companies. The same separation between the western and eastern production regions was also included in the simulating experiments. This differentiation between the eastern and western production regions was important in the lead up to the data collection and, thus, the two study sites were selected. The Pannar discrepancy between east and west was used for the simulating experiments as well as the case study. Figures 5.6 and 5.7 show the two production regions.

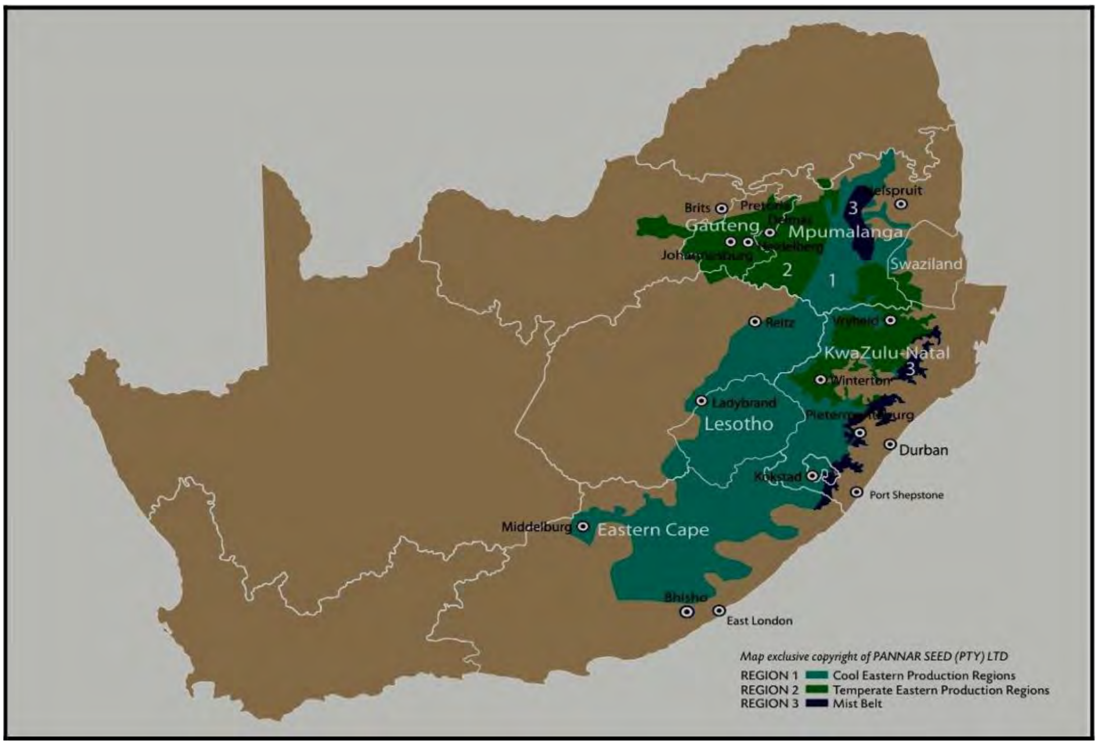

Figure 5.6: Eastern production region (Pannar, 2020)

The study made use of two commercial maize regions, one in each of the production regions. Initially, it was expected that cultivars would make a difference between the two regions. However, following the results from the simulating experiments and no clear cultivar use pattern among the farmers during the data collection, it was decided to rather group the data by region (east vs west) and variety (yellow vs white).

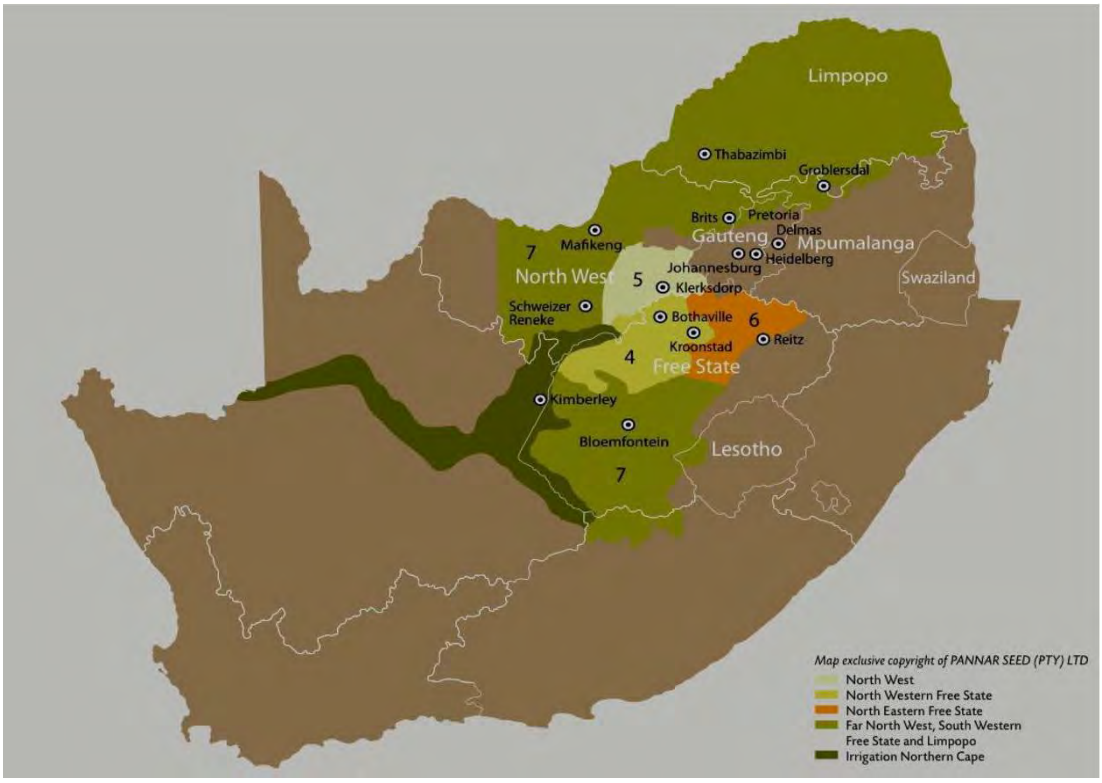

Figure 5.7: Western production region (Pannar, 2020)

Tables 5.2 and 5.3 below depict the responses by the farmers to the questionnaire during the interviews conducted between December 2019 and January 2020.

Table 5.2: Questionnaire response for the West

	Farmer 1	**Farmer 2**	**Farmer 3**	**Farmer 4**	**Farmer 5**
Variety	White and Yellow	White	White	White	White and Yellow
50% annual income	✓	X	✓	✓	X
Other crops	Soybeans	Soybeans, Sunflowers	Sunflowers	Sunflower, groundnut and cover crop	Lucerne
Annual Maize Production (t/ha)	5,5	5 - 6	5 - 6	6,5	2,5 - 10
Revenue (R) (2019)	22 million	14,4 million	15 million	16 million	140,07 million
Size of cultivated land under maize (ha)	1541	1200	970	1200	14000
Cost of Production (R/ha)	13000	9000	5000	5000 - 6000	7500
Change Cost of Production	Increased	Increased	Increased	Increased	Increased
Intention to Increase/Decrease	Increase	None	Increase	None	None
Climate changes					
Heat	✓	✓	✓	✓	✓
Drought	✓	✓	✓	✓	✓

Change in rainfall patterns	✓	✓	✓	✓	✓
Other	X	X	X	X	X
Simulating experiments					
Improved WUE	Agree	Agree	Agree	Neutral	Agree
Accelerated Growth rates	Neutral	Agree	Agree	Neutral	Agree
Increase in yields	Agree	Agree	Agree	Agree	Neutral
More lenient planting dates	Disagree	Disagree	Disagree	Disagree	Disagree
Benefits from CC	X	X	X	X	X
Changed management strategies	✓	✓	✓	✓	✓
Adaptation methods					
Changed planting dates	✓	X	✓	✓	✓
Change in variety	X	✓	✓	✓	✓
Introduction/increase in irrigation	✓	X	X	X	✓
Fertiliser	X	X	X	✓	X
Changed planting methods	X	✓	✓	✓	✓
Reduction in emissions	X	✓	✓	✓	✓
Other	✓	X	X	✓	X
Have the adaptation techniques worked?	✓	✓	✓	✓	✓
Biggest climate factor	Rainfall	Extreme heat	Heat	The extreme weather patterns	Changing season

Table 5.3: Questionnaire response for the East

	Farmer 6	Farmer 7	Farmer 8	Farmer 9	Farmer 10
Variety	Yellow	Yellow	Yellow	Yellow	Yellow
50% annual income	X	X	X	X	X
Other crop	Soybean, teff, sunflowers	Sunflowers, teff	Soybeans, sunflowers and teff or oats	Sunflowers, teff	Sunflowers and wheat
Annual Maize Production (t/ha)	4	1 - 4	4,5 - 5	3,5 - 4	4
Revenue (R) (2019)	3.7 million	808 641	14,875 million	Unsure	2.5 million
Size of cultivated land under maize (ha)	500	107	850	200	300
Cost of Production (R/ha)	4000	2774	7500 - 8000	3500	7500
Change Cost of Production	Increase	Increase	Increase	Increase	Increase
Intention to Increase/Decrease	Increase	No	Increase	No	No
Climate changes					

Heat	✓	✓	✓	✓	✓
Drought	✓	X	✓	✓	✓
Change in rainfall patterns	✓	✓	✓	✓	✓
Other				✓	
Simulating experiments					
Improved WUE	Agree	Disagree	Agree	Neutral	Neutral
Accelerated Growth rates	Disagree	Neutral	Undecided	Neutral	Neutral
Increase in yields	Agree	Disagree	Agree	Agree	Neutral
More lenient planting dates	Disagree	Disagree	Disagree	Disagree	Disagree
Benefits from CC	X	X	X	X	X
Changed management strategies	✓	✓	✓	✓	✓
Adaptation methods					
Changed planting dates	✓	✓	✓	✓	✓
Change in variety	✓	✓	✓	✓	X
Introduction/increase in irrigation	✓	X	X	✓	X
Fertiliser	✓	X	X	X	X
Changed planting methods	✓	✓	✓	✓	✓
Reduction in emissions	✓	✓	✓	✓	✓
Other	X	X	X	✓	✓
Have the adaptation techniques worked?	✓	✓	✓	✓	✓
Biggest climate factor	Heat	Heat	Heat and drought	Heat and drought	Rainfall patterns

5.3 Maize varieties

One of the management decisions that a farmer faces at the beginning of any planting season is the cultivar package that they will cultivate. Climate change plays a significant role in the decision of the cultivar package. The emergence of more drought resistant hybrids, for example, shows how cultivar producers are adapting their cultivar packages to climate change. When selecting their ideal package, the farmer must consider the yield potential of the cultivars, their risk management (only planting one cultivar is extremely risky, for example). Additionally, the agronomic characteristics of the cultivar and how resistant it is to drought, diseases and pests are also extremely vital (Pannar, 2019).

The type of cultivar is dependent on the crop season. The length of the growth season and the availability of water determine which cultivars will be preferred over others (Jaidka et al, 2019). Each cultivar will have its own ability to adapt to certain conditions and a different yield potential (Du Plessis, 2003). Therefore, cultivar choice can make a huge contribution to the reduction of overall risk of the crop and is a vital part of maize production (Du Plessis, 2003). The choice of cultivar needs to be revised every production season due to the changing climatic conditions.

All the farmers interviewed cultivated more than one type of cultivar and there was no clear consistency between cultivar types or producing companies. Pannar, Pioneer and Dekalb were the most common companies with most farmers opting for a cultivar package ranging across producers.

In the lead up to the farmer questionnaires, it was expected that cultivars of maize would be noticeably different between the western and eastern regions due to the different conditions they areexposed to, and, additionally, cultivars are produced with western and eastern regions being treated separately. However, what was not anticipated was the clear distinction between the western regionmainly producing white maize and the east mainly producing yellow maize. Initially the project was expecting to find cultivar differences, but this assumption was soon changed to differences in varietiesrather than cultivars when it became clear that the biggest discrepancy between the east and west was variety differences rather than cultivar differences.

Yellow maize tended to be the most popular variety in the east with little white maize being produced. The west, however, was found to have a greater variety with the farmers opting for a mixture of white and yellow maize with white being the main variety selected. Yellow maize is a much faster growing variety in both regions, but the farmers felt that white maize produces a bigger crop, on average, but has a much slower growth rate than the yellow maize. Due to the slower growth rate, white maize is generally planted earlier on in the planting window with yellow maize being planted later. Farmers in the east have recently started planting their maize later due to the changing climatic conditions. As a result, yellow maize has proven to be the most popular variety choice.

The west, however, plant their maize slightly earlier than their eastern counterparts and make use of the higher yield potential that the white maize seems to offer. However, by the end of the planting window, they too, revert to more yellow maize.

5.4 Portion of income from maize

Due to most of the land area of the Free State falling under the western production region it is no surprise that it was easier to find larger commercial farmers in the west than the east. As a result, the farmers interviewed were generally farming on a much larger scale in the western region than the eastern region. None of the farmers from the east had more than 50% of their annual income from maize production. However, 3 out of the 5 western region farmers had maize as their main source of income.

Farmers in the eastern region had a more varied make up of agricultural production. Not only do the farmers have more variety between crop and livestock farming but also variety within their crops and livestock, which is discussed in more detail in 5.5. The biggest producer interviewed from the east received approximately 30% of his annual income from maize. He did, however, plant sunflowers on a similar scale as well as some soybeans so crop farming is still his primary income source.

The size of cultivated land showed the difference in scale between the eastern and western farmers interviewed. The average cultivated land size of maize in the east is much smaller than the west with none of the farmers interviewed growing more than 850ha. The west however, averaged well over 1000 hectares of production per farmer with all the farmers growing at least 1000ha. When analysing the difference in scale of production it comes as no surprise that the portion of the annual income for farmers for the east is much smaller.

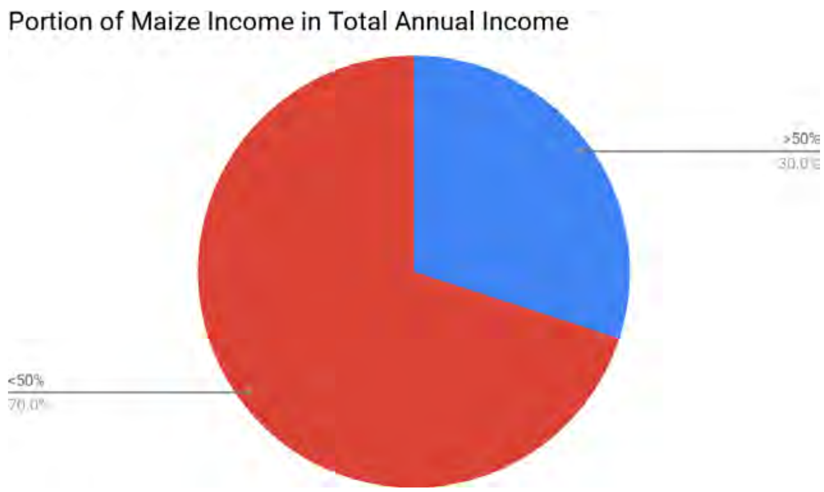

Figure 5.8: Portion of maize income to total annual income (Adapted from questionnaire)

Figure 5.8 represents the portion of farmers whose maize income makes up at least fifty percent of their total annual income of their farm. Most of the participants receive less than fifty percent of their annual income from maize. Due to the volatility of the climate, the participants felt that it was too risky to rely too much on maize as their primary source of income. This is especially true for the eastern region of the province where the climate allows for more diverse farming allowing the farmers to spread their risk over multiple income sources. The three participants who do receive more than fifty percent of their income are all from the western region where the climate is less forgiving to other sources of agriculture. Additionally, the three farmers are all farming on a much larger scale than any of the farmers in the east, reinforcing the belief that size matters in maize production. Large scale maize farming and its opportunity of economies of scale diminishes the risk of climate change (Dean, 2018; Greenberg, 2015).

5.5 Other crop cultivation and livestock

As in any industry, diversification is important in agriculture. All the farmers interviewed grew other crops and had livestock on their farm to generate extra revenue and to serve a second purpose. As already mentioned, the farmers in the east were more equally spread between their maize production, their livestock and production of other crops. Figure 5.9 below shows the other crops that are produced by the participants in the study.

All 5 of the eastern region's farmers grew other crops on a similar scale to that of their maize. Additionally, their livestock component of their farming is much larger than those in the western region. Their livestock is made up of sheep and cattle. Although the farmers in the eastern regions are producing maize on a much smaller scale, they have a wider variety of crops and livestock than the farmers who participated in the study from the western region of the province.

An interesting observation shared by some of the participants while the interviews and questionnaires were being conducted was that maize is an ideal crop to cultivate due to its ability to get a second use out of it. Maize leaves behind more residue than sunflowers, for example, and as a result, a farmer who has livestock can feed their animals on the residue of the maize. Farmer 3 from the east suggested that if maize did not leave extra residue for food, he would not grow maize at all but would prefer to have sunflowers only. The economic value of maize, therefore, is more than just the income received from producing it.

Figure 5.9 shows that sunflowers were the most popular additional crop with 8 out of the 10 farmers growing sunflowers. Teff and soybeans were the next most popular with 4 farmers each. Interestingly, all the farmers producing teff were in the eastern region.

In addition to sunflowers, soybeans and teff, wheat (1), oats (2), alfalfa (most commonly known as lucerne) (1) and groundnut (1) is produced by the farmers included in the study.

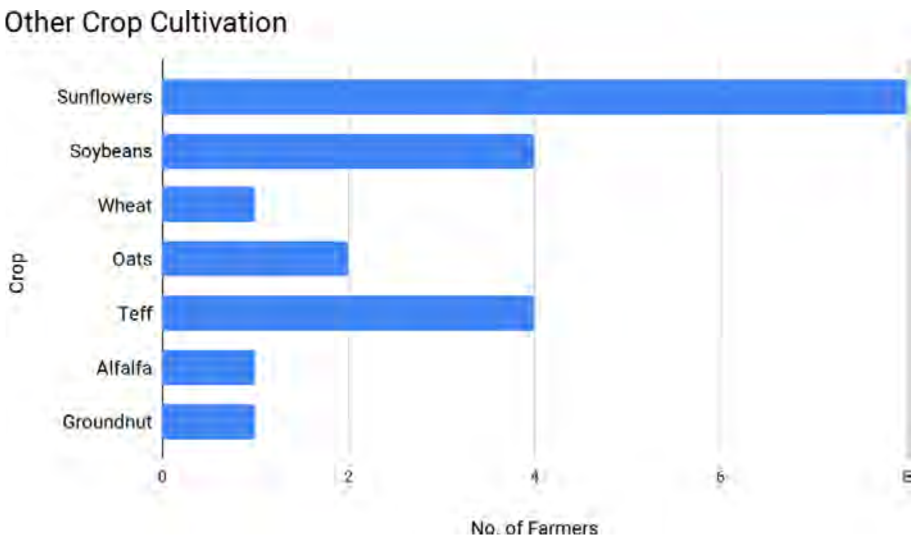

Figure 5.9: Supplementary crops cultivated (Adapted from questionnaire)

5.6 Output

Climate change has the effect of increasing CO_2 levels in the atmosphere and is believed to improve the capacity of C4 plants like maize to produce more output. Simulating experiments and literature suggest that increased concentration levels of the gas are not only improving the efficiency of their water use but also in the crop that they are producing. The questionnaire recorded the output produced by the farmers who participated in the study in tonnes per hectare and the participants were asked if they had noticed any changes in the output to assess whether increases in output were indeed occurring.

The western region achieved higher yields per hectare than their eastern counterparts. On average, the western farmers produced between 5 and 6 tonnes per hectare. However, irrigation would make a huge difference to their yields. Farmer 5 grew a portion of his maize under irrigation and achieved nearly 10 tonnes per hectare.

The eastern farmers tended to only achieve around 4 tonnes per hectare. The lower yield per hectare as well as the smaller scale of production found in the region has resulted in their turnover to be much lower. However, the costs of production in the east is much lower than producing maize in the west which is addressed in 5.7.

The consensus by the farmer participants was that output has been increasing gradually over time. However, all the farmers have had to adapt their management and production strategy somewhat to achieve the increase in their yields. For the most part, many farmers have attributed this growth of maize output over the country to the improvements in seed technology. Although, following the findings of the various simulating experiments conducted around the world as well as the experiments conducted by the Rhodes University Botany Department, the increase in the atmospheric concentration levels of CO_2 could be playing a role.

5.7 Costs of Production

The positive impact of elevated levels of atmospheric CO_2 on maize plants has been well documented and discussed by this research paper. However, the impact of the knock-on effects of CO_2 related climate change and the rapid rise in costs of production for maize farmers is what the paper aims to investigate. The forced increase in the costs of production to produce maize and the subsequent changes in the commercial maize market is the real economic impact of climate change and not the increases in yields attributed to the plants being subject to eCO_2.

The farmers who participated in the research were asked about their costs of production and whether the climate has changed the costs at all. The increase in costs generally arose because of changes that they felt that they had to make to ensure that maize production was a sustainable sourceof income. These adaptation methods are discussed in more detail in 5.8.

The costs of production varied greatly between the farmers and no clear pattern emerged of higher costs of production resulting in higher yields. There are, naturally, unavoidable costs associated with maize production like purchasing seeds to plant and the rise in diesel prices which are not associated with climate change. Additionally, there are costs that, simply, come with geographical positioning when a farm is not situated in an ideal climate for maize production. The research, though, focused on the costs that farmers have been forced to increase because they have been subject to intense heat or drought. As in any sector, farmers are profit maximisers, attempting to minimise their costs whilst maximising their output.

The costs of production from the two regions were difficult to analyse due to the wide range of the results. Generally, the eastern region produced their maize at a much lower cost, ranging from just over R2500 per hectare to R8000. This came as no surprise due to the area being situated in an area that is less hostile. The western region incurs much bigger costs to achieve their yields. The range of costs of production is between R5000 and R13000 per hectare.

The one constant with regards to the costs of production from both regions is that they have increased. All 10 of the farmers have found that their costs of production have been increasing over time. An interesting observation was whether costs of production increased relative to their output or annual income. The participants felt that, initially, their costs of production increase dramatically relative to their output due to the large investment required to increase the scale of their production or to counter the negative impacts of climate change. However, the larger farmers have found that after their initial investment and large increase in costs of production their costs have increased at a much slower rate to what their costs would have been had they not made that initial investment.

The increases in the costs of production could be attributed to the weakening of the rand in relation to the world currencies as the price of diesel, fertiliser and chemicals fluctuates with the Rand/Dollar exchange rate as well as the increase in the minimum wage in South Africa. However, it was found that although there are economic factors to explain some of the increases in the costs of production, the need to adapt to the harsh climate that the farmers are having to deal with is the biggest expense. In some of the cases, farmers have had to completely change their practices which has required new machinery.

The result of the forced additional costs that are required to adapt, maize producers are having to increase their scales of production to justify and fund the costs of the new methods and machinery. Ensuring that maize is a sustainable source of income demands an increase in investment and the farmers who are already on a larger scale can afford to make this investment. However, the smaller scale farmers who cannot afford to increase their investment move onto another form of farming that is less reliant on the climate.

The question of whether the farmer had any intention to increase their scale of production proved to be interesting when discussing the costs of adapting. Four of the participants, two from each region, were wanting to increase the scale of their production. The two from the eastern region were the two biggest producers and both had recently purchased new machinery as an adaptation technique. The new larger machinery allowed them to plant more of their crop in a shorter space of time and to justify investing in the larger machinery, a bigger scale of production was necessary. Additionally, when asked what their ideal size of land planted to maize they would like to achieve, both said around 1000 hectares.

The west, however, as already mentioned earlier in the chapter, produces maize on a much larger scale. All the farmers interviewed were already producing at the 1000 hectare goal set by the larger eastern region farmers. The two farmers wanting to increase their production had already upscaled their production to cope with the additional challenges but were now wanting to upscale again since their initial growth of production had been successful.

5.8 Adaptations

The techniques adopted by each farmer to adapt to their climate challenges are where the costs of production between farmers became inconsistent. The most used adaptation techniques used by the farmers were changing their planting dates and changing the method of planting, with 9 out of the 10 farmers adopting these techniques. The changes in planting dates involved delaying the start of planting and planting later than the historical planting season of the region as well as adopting more conservational tillage where they worked the land less frequently before planting their maize.

The change from the established conventional planting and tilling practices to a more reduced or zero tillage system requires higher management inputs and control, adapted or specific planters and more expensive equipment. The equipment includes machinery that is capable of multiple operations. Instead of working the land numerous times in the lead up to the crop being planted, farmers are moving to a more cost effective and environmentally friendly practice because of the lower fuel consumption and the quicker adaptation to the optimum planting dates. Whilst this method is cost effective and more efficient in the long run because less machinery is required, it does require a sizable investment to start as one has to purchase new machinery or adapt the old machinery. Not only is this allowing reduced emissions, but the sheer size of new machinery allows for the work to be done much quicker allowing for more crop to be planted in the shorter windows.

A change in the variety was also a popular adaptation technique adopted with 8 out of the 10 farmers using this adaptation technique. This was more frequent in the east where the farmers' most common variety is yellow maize as it is a quicker growing variety. Although white maize tends to achieve higher yields, the fact that farmers are planting much later than before has resulted in them being forced to opt for the quicker variety. In the west, although white is still the dominant variety being planted, yellow maize is planted at the end of their planting window. This too is because it is believed to be a quicker growing variety so planting later has less of an impact.

The adaptation techniques termed as "other" in the graph below generally relate to weed control. This was an adaptation technique that the project did not originally consider and was, therefore, not included in the questionnaire but was revealed through the interviews. Whilst it is not an adaptation to climate change, it has played a role in the mitigation as farmers move away from mechanical weed control which results in them using up less diesel and emitting less CO_2 into the atmosphere. However, by moving away from mechanical weed control where the farmers would previously plough up the weeds in the soil, they now must increase the number of chemical herbicides. Unfortunately, this is an additional cost that farmers are having to incur.

It is difficult to conclude and definitively state which adaptation techniques are the most successful as each farmer is faced with different challenges. However, following the interviews, it is evident that the maize farmers in the current climate are planting their crop later, are working their land less frequently than they were in the past and are generally planting a different variety, or at least some of their crop is a different variety. They are also aware of the more specific challenges that their farm has that they need to adapt to. Additionally, they are constantly looking for ways to make their production more specific.

The interviews did reveal, however, the adaptation techniques which are not as necessary as originally believed. Whilst irrigation does increase yields, farmers are still managing to achieve increasing yields without it. Changing the amount of fertiliser is also an adaptation technique which does not seem to be necessary. The additional costs that would be incurred is not worth investing in, especially when one considers the findings of the simulating experiments which reveal the CO_2 fertilisation effect as well as the water use efficiency of maize plants under elevated CO_2.

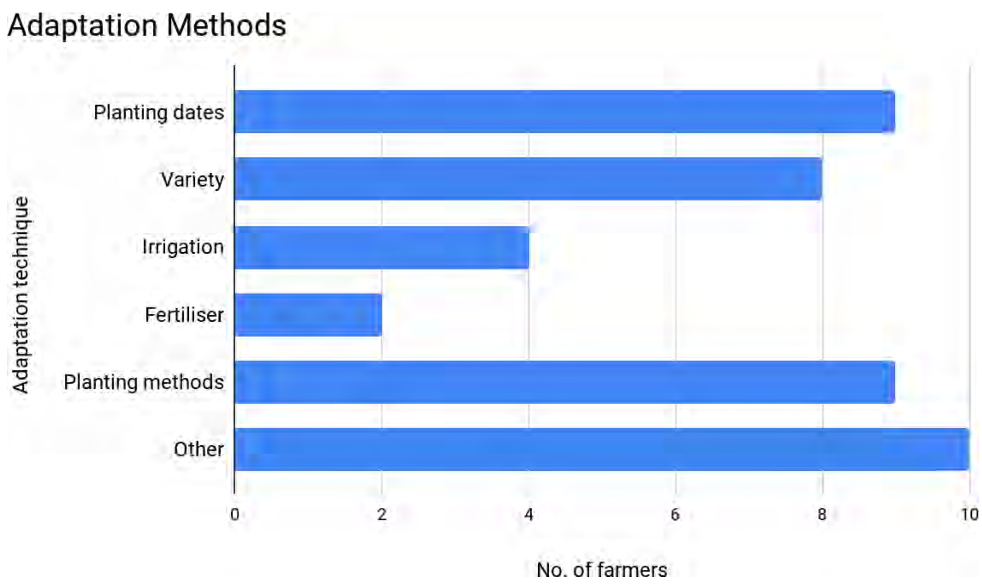

Figure 5.10: Adaptation methods used by farmers (Adapted from questionnaire).

The research project aimed to expose the changes in maize farmers' behaviour in the Free State. The changes in their behaviour is an indication of a change in the climate as had there been no change in the climate, they would not be changing their behaviour.

As already mentioned, and presented in figure 5.10, the two most popular adaptation techniques used were changing the dates of their planting and the method of their planting. These changes in the behaviour clearly indicates a change in climate when one delves into why these behavioural changes were made.

Farmers have been planting their maize later than the historical planting period due to a change in the timing of the rain. The usual early summer rain has been inconsistent and has been falling much later into summer. The later rainfall is even more evident in the eastern region of the Free State, which was renowned for its production of wheat. Now, only one farmer in the region still produces wheat.

The change in rainfall patterns is reinforced when one considers the increase in the reduced and zero tillage planting methods. Farmers are not only reducing their tillage due to the reduction in costs of diesel through working their soil less frequently, but also because it increases the residue on the surface of the soil which decreases the rate of evaporation from the soil, thus maintaining the soil moisture levels for longer periods. When the usual summer rainfall was occurring, farmers did not have to try to maintain the soil moisture levels because there was frequent and early summer rainfall. However, with the delay in the rainfall season and the inconsistency of the rainfall, the risk of the maize running out of moisture in its growth phase is much higher.

The results of the impact of eCO_2 in the simulation experiments came as a surprise to most of the farmers interviewed. The changes in their behaviour, even in cases where their changes made use of the positive impacts of higher levels of CO_2 on maize cannot be attributed to their knowledge of the effects.

5.9 Gross Margin Analysis

Following the interviews, a gross margin analysis was conducted on each farmer in the study. When this method was adopted, the project did not anticipate the varied accuracy of record keeping by the farmers. The figures that the farmers gave were, for the most part, approximations. Additionally, because all the farmers have additional income accruing activities on the farm with their own expenses associated specifically to those activities, it was difficult for them to isolate some of the costs to just maize production. Diesel, for example, is a cost of production for maize production but the farmer also uses diesel and machinery for other farm activities.

The table 5.4 below shows the gross margins and the market efficiency of each of the farmers included in the study. Farmers 1 through 5 are from the western production region and farmers 6 through 10 are from the eastern production region. Farmer 9 was excluded from the gross margin analysis as the revenue figures were inaccurate. During the interview farmer 9 revealed that the revenue figure given was of the entire farm's operation and not just from the maize production.

The figures were calculated using the formulas addressed in Chapter 3 for gross margin and market efficiency.

Table 5.4: Total gross margin for maize production and market efficiency

Regions		Total Gross Margin	Market Efficiency
West	Farmer 1	R 1 967 000	91,06 %
	Farmer 2	R 3 600 000	75 %
	Farmer 3	R 10 150 000	32 %
	Farmer 4	R 9 400 000	41,25 %
	Farmer 5	R 35 070 000	74,96 %
	Average	R 12 037 400	62,85 %
East	Farmer 6	R 1 700 000	54,05 %
	Farmer 7	R 511 823	36,71 %
	Farmer 8	R 8 500 000	42,86 %
	Farmer 9	N/A	N/A
	Farmer 10	R 250 000	90 %
	Average	R 2 740 455,75	55,91 %

The gross margin allowed for a comparison between the producers of each region. The gross margins of the farmers in the western production region were considerably higher than their eastern counterparts. This was not surprising as their scale of production is much higher. On average, the gross margin in the west was R12 037 400. The average gross margin in the east was only R2 740 455,75.

To have a comparative analysis of the two regions, the gross margins were brought to a common denominator where the gross margin was compared per hectare. The per hectare gross margin was calculated by dividing the total gross margin by the number of hectares produced and is presented in table 5.5 below.

Table 5.5: Gross margin per hectare

Regions		Gross margin per hectare
West	Farmer 1	R 1 276,44
	Farmer 2	R 3 000,00
	Farmer 3	R 10 463,92
	Farmer 4	R 7 833,34
	Farmer 5	R 2 505,00
	Average	R 5 015,74
East	Farmer 6	R 3 400,00
	Farmer 7	R 4 783,39
	Farmer 8	R 10 000
	Farmer 9	N/A
	Farmer 10	R 833,34
	Average	R 4 754,18

There are two outliers in the gross margin per hectare (GM/ha) analysis, farmer 3 had a GM/ha of R 10 463,92 and farmer 8 had a similar GM/ha of R 10 000. Interestingly, both farmers have adopted the zero tillage planting method. Farmer 3 had the lowest cost of production per hectare from the western region on 970 hectares of maize planted and achieved a yield that is similar to the other farmers in the region. Farmer 8 is the largest maize producer interviewed from the east planting 850 hectares and achieved a yield per hectare that was larger than the other farmers from the region. Additionally, farmer 8 has been utilising the zero tillage planting method for well over 10 years, so believes that his increase in yields can be attributed to a long term build-up of organic matter in the soil and a lower soil evaporation rate due to the plant residue left on the surface of the soil.

Through analysing the gross margin per hectare, the difference between the average gross margins of the two regions is reduced. The western region still achieves a higher gross margin per hectare, on average, than the eastern region but only by R 261,56 per hectare compared to the huge difference of R 9 296 944,25 in the total gross margin. The per hectare gross margin is therefore a more accurate comparison of the two regions.

However, according to Abdullahi et al. (2017), one should not compare enterprises of different characteristics. Considering this, it is unfair to compare the west to the east solely on their gross margins due to the different characteristics of the farms. The market efficiency is, therefore, a more realistic comparison of the two regions.

The market efficiency shows the percentage of the revenue taken by the costs of production (Shephard et al, 1982). The figure shows which farmers and regions are the most efficient producers. On average, 62,85% of the revenue is used up by costs of production in the west. The east, however, averages 55,91% market efficiency. Thus, the east has, on average, a more efficient production of maize.

The two outliers, farmers 1 and 10, have a market efficiency of 91,06% and 90% respectively, which means that 91,06% and 90% of their income goes to expenses. In the case of farmer 1, the inefficiency of production is offset by the scale of production as the farmer still achieves a gross margin of close to R2 000 000. Farmer 10, however, does not have the scale of production to offset the high cost of production. Unlike farmer 1, maize production is not the main source of income for farmer 10. Maize is a subsidiary to livestock production.

5.10 Conclusion

Elevated levels of CO_2 in the atmosphere does have a positive impact on the production of maize. Through CO_2 fertilisation, plants are growing at a much quicker rate and their capacity has increased. However, at the current levels of CO_2 in the atmosphere, the plants are saturated, so the impact of CO_2 fertilisation is not an exponential one. The simulating experiments discovered another positive impact of elevated CO_2. The plants have been found to be more efficient in their water use and are more resistant to drought as a result. The potential economic impact of elevated CO_2 on maize production in the Free State lies in the impact of the improved WUE by the plants. The experiments suggest that it will completely offset the negative impacts of climate change. However, the findings of the case study suggest we are not yet at that stage.

In the case study, the farmers in the west produced around 6 tons per hectare at an average cost of production of R8000 per hectare. The average cost of production in the east was much lower at R5155 per hectare but so too was their production at around 4 tons per hectare. The biggest difference between the two regions, however, was the average size of cultivated land with the west having an average cultivated area of 3782 hectares. This figure is skewed due to farmer 5 growing significantly more than the rest of the farmers interviewed. A more accurate representation by excluding farmer 5 is an average of 1228 hectares in the west. The east had an average of 391 hectares with the largest producer still being below the average of the west.

The case study showed the contrast between the two production regions of the Free State. The western region produces maize on a significantly larger scale to the eastern region despite having a hotter and drier climate. However, the costs of production in the west are much higher, which was represented by the region having, on average, a lower market efficiency. The east is more efficient than the west in their production, but due to economies of scale the west is a more successful region of production. Although most of the farmers were unaware of the impact that elevated CO_2 would have on maize, most of the farmers have found that maize is more resistant and that their yields have increased.

Adaptation, as Schulze (2016) predicted, is indeed the centre of the economic debate. Farmers have had to adapt to the change in their maize season as it has become shorter with later summer rain. The window in which farmers must plant their crop has become shorter so the use of larger and more efficient machinery has become imperative if one wants to compete in the market. The most common adaptation techniques are changing variety, changing methods and changing planting dates. Farming maize has become more expensive, particularly when one considers the negative impacts of climate change and the need to adapt.

The biggest climatic challenge that farmers have experienced is the heat. Extreme heat and longer periods of drought have affected all farmers. Even farmers who can irrigate some of their fields struggle as the cost of irrigation has increased due to high electricity bills. Extreme heat also means that they must irrigate a lot more than usual. The drought also affects them as the level of water in their dams that they irrigate out of is depleting at a rapid rate.

CHAPTER SIX

Discussion, Conclusion and Recommendations

6.0 Introduction

This concluding chapter gives a summary of the project, the conclusions drawn from the findings and the recommendations for future studies. The chapter is divided into 4 sections. First, the chapter addresses the findings of the study noted in the previous chapter and discusses what the economic impact of these findings means for maize farming in the Free State (6.1). Secondly, a summary of the project is given (6.2). Thirdly, the project did fall short in certain aspects and these shortfalls are addressed with the limitations placed on the project as well as the assumptions that were made. The shortfalls, limitations and assumptions are discussed in 6.3. Finally, 6.4 gives a conclusion and recommendations for future research on the topic.

6.1 Discussion

Elevated levels of CO_2 have a host of environmental and economic effects. Most of the literature on the topic discusses the effect on the plant and the improved capacity (chapter 2). However, the economic effect is more complicated. Several attempts have been made to understand the economic consequences of climate change on maize in the country (Nxumalo, 2015; Sibanda et al. 2006).

The economic effect can be estimated in one of two ways. Firstly, one can understand the effect that elevated CO_2 has on the production of maize and the economic effect can be estimated through the increases or decreases that result. Alternatively, the economic effect can be analysed by the changes that elevated CO_2 and the subsequent climate change has caused in the maize farming industry. This research project adopted the second approach.

It was recognised that the increasing levels of CO_2 in the atmosphere has the potential to increase yield due to its water saving potential. Simulating experiments in the literature review (Chapter 2) and the experiments conducted by the Rhodes University Botany Department (Chapter 4) investigated the impact that higher levels of CO_2 has on maize.

However, one of the most influential economic effects of climate change on the production of maize in the Free State is that the ideal season for maize production has become shorter. The change in the recognised planting and growing season has significantly affected the maize industry.

Farmers have found themselves with a much shorter window in which they must plant their crop. This is due to the summer rain falling much later in the year. Additionally, because the costs of production have increased, farmers are also being forced to increase their production area to ensure that maize is a viable economic option for them.

This has forced maize farmers into a corner where they find themselves in a situation where they must plant more maize in order to combat the increase in the costs of production, but they have a shorter time frame in which to achieve this. Fortunately, technological advancements allow farmers to plant a larger area of land in a shorter period. Modern cropping equipment not only improves speed of planting but also their efficiency. This equipment also can complete multiple tasks simultaneously and more efficiently meaning that farmers can be more accurate with their planting and save costs. Unfortunately, significant capital is required.

However, yields have been increasing. Many of the farmers believe that this is due to new varieties and cultivars being more resistant to drought. But this could also be due to the elevated CO_2 effects discovered through the simulations. Whilst the reason for the improved yields is up for debate, the country is producing more maize. Higher yields result in a bigger gross margin and improved profitability allowing for an increase in production for the following season.

Yet, smaller commercial farmers in the east are being pushed out of the market. This is due to maize production becoming more expensive and as a result, in order to make enough profit to consistently produce maize, farmers are having to produce on a much larger scale. The bigger commercial maize farmers in the west can expand their production, even though their climate is less conducive asthey can adapt to the changes. The smaller farmers in the east get caught in a cycle where they cannot compete in the market because they cannot afford to upsize. This has resulted in the western commercial maize farmers growing their maize production whilst the eastern farmers are moving to a more diversified production on their farms.

According to Venter (2020), it comes as no surprise that the grain industry has experienced challenges over the last few crop seasons. In the main production regions (Free State, North West and Mpumalanga) maize was planted outside of the optimum planting window this season. The climate dictated that the farmers either planted their crops later than usual and face the risk of frost or not plant a crop at all.

Additionally, the crop's profit margins are also under pressure due to the rapid increase in supply from the increase in scales of production. The demand for maize, however, did not increase at the same rate and maize prices, internationally, are where they were around 10 years ago (Venter 2020). The rise of production costs in adapting to climate change has caused an environment where maize farmers are left with no margin for error. Maize farmers must produce the most optimal crop by using the resources available in the most efficient way possible to achieve the highest possible yield and the lowest possible input costs.

6.2 Summary

The research paper attempted to make an evaluation on the economic impact of climate change on maize production and how it can be measured. Using literature on studies on the impact of elevated levels of CO_2 on C4 plants and the results of an in-house simulating experiment by the Rhodes University Botany department, the project had a basis in which to compare what is expected to happen in the future to the current situation of maize production.

The literature review found that CO_2 fertilisation, a resultant positive effect of the increased concentration of the gas, helps to alleviate the harmful impacts of climate change. However, maize production in South Africa is still sensitive to the changes of the climatic conditions as a direct result of these higher concentrations of CO_2 in the atmosphere. Therefore, the research project investigated previous studies on the effects of elevated CO_2 and climate change and found that marginal changes in temperature and precipitation affect grain production.

The findings of previous studies showed that marginal changes in temperature and precipitation are, on average, similar across the country and the crops reviewed. Increased temperatures in the cooler seasons improve revenue, on average, and an increase in precipitation results in improved yield. The studies all highlighted that these results were obtained by farmers who have used adaptation techniques to combat the challenge that is climate change. Without adaptation, the beneficial impact of CO_2 fertilisation is insignificant in comparison to the negative consequences of climate change.

Through exploring the topic more and seeing the results of the simulating experiments, it was clear that the impact of elevated CO_2 on maize plants is generally quite positive (Li et al. 2018; Lobell et al. 2011; Leakey et al. 2006; Markelz et al. 2011 and Erda et al. 2005), albeit not in the manner expected. However, whilst the results of simulations of elevated CO_2 in the atmosphere may give the impression that maize production should be flourishing, there are some negative consequences associated with the higher concentration of the gas. Extreme heat and inconsistent rainfall, proof of the ever-changing climate, are the two most prominent of these negative consequences according to the maize farmers interviewed. Therefore, there seems to be a trade-off between the positive impacts found in the simulating experiments and the negative consequences of climate change.

This trade-off relates to the disruption of farming practices, a concern raised by Schulze (2016) and the extent to which current farming practices must be changed. The economic impact of climate change is, therefore, the changes in the current farming practices because of the change in climate.

Chapter 4 explored maize production in South Africa. The country produces maize because it experiences the ideal climate, it is a profitable agricultural industry and it is a vital food source for much of the population. The chapter continued by highlighting that the country generally experiences the ideal climate for maize in the highveld areas with the Free State, Mpumalanga and the North West consistently producing most of the maize in South Africa. This was revealed to be very important to the country not just economically but also to the future of food security because if the climate of these three provinces were to be affected significantly and disrupt the maize production, the maize industry in South Africa would crumble.

Higher concentrations of CO_2 benefit the production of grain production in South Africa, provided that there is some level of adaptation to the changing climate. The aim of mitigating the negative consequences and taking advantage of the positive consequences is the key to the longevity of grain production.

Adaptation to the changing climate, is therefore, the focus of maize farmers' future in the industry. As Schulze (2016) predicted, the effect of elevated CO_2 should be seen through the change in the level of productivity as well as the disruptions to the farming operations. The research showed that the shifting from conventional tillage to a more reduced tillage method or to a completely zero tillage production is the biggest adaptation technique that farmers are making. The interviews also found that there has been a shift in the optimum planting window and as a result, farmers are adapting by planting their maize much later in the year. Furthermore, farmers have changed their variety of maizeand have had to adapt their weed management strategies.

However, the results showed that the impacts vary across different regions, so adaptation techniques cannot be uniform across South Africa. CO_2 fertilisation is best taken advantage of with the most effective adaptation methods. The research also revealed that these adaptation techniques cannot be used in isolation. An example is the two most used adaptation techniques where farmers are reducing their tillage and purchasing larger and more specific machinery allowing for them to plant their crops later and within a much smaller planting window. Farmers are required to use more than one method of management.

The economic impact of climate change on maize production is the cost of the changes in production. Furthermore, the changes in the maize production environment brought through the changing climate and the forced adaptation by maize farmers is also significant when discussing the economic impact. The exponential rise of costs of production due to the need to adjust to the ever-changing climate has resulted in the commercial maize industry in the Free State being dominated by the larger farmers. The overwhelming majority of these larger maize farmers are found in the western region despite experiencing a more hostile climate and the smaller farmers in the east suffering from diminishing marginal returns if they fail to upsize like their western counterparts.

The small margin for error in the farmers ability to upscale, produce maize in the optimum and most efficient manner whilst still achieving increasing yields has caused the market to shrink in its number of producers. The supply of maize is increasing, but the number of suppliers is decreasing.

6.3 Limitations, Assumptions and Shortfalls

The results of the research need to be understood within the context in which they were studied, and the limitations placed on the research. The context and limitations exist due to some research challenges that were encountered. To assess the economic impact, one requires a reasonable level of assumptions related to elevated CO_2.

The relationships and models reviewed on the impact of elevated CO_2 on maize are broad and possibly specific to the area in which they were conducted. They were, however, necessary in understanding how elevated CO_2 could affect maize in the future.

The project accepts the validity of climate change and its causes. The project undertook the assumption that climate change is undeniable and that it is being caused by an increase in the concentration of greenhouse gases in the atmosphere with CO_2 being the most commonly accepted culprit due to excessive emissions of the gas (DEA, 2011). The research project does not assume to be qualified to debate climate change and its validity.

The Free State province is confirmed to be the largest maize producing province in South Africa (Greyling and Pardey, 2018). As a result, to accurately report the average financial figures of maize production one would need a much larger sample size than the one for this project. The sample size required would demand more time and funding than available for this research paper. To combat this challenge, a case study was used which allowed for an understanding of the costs of maize production and how it has been affected by climate change.

The context of the case study is based on the personal experiences of the farmers included in the study and their opinions. These experiences and opinions are not assumed to be unanimous across the region. It is recognised that the case study approach is not as accurate as a large sample group.

A shortfall of the project that became evident during the interviews was the exclusion of the impact of heat stress on maize in simulating experiments. The simulations reviewed as well as the experiments conducted by the Rhodes University Botany department accounted for the drought stress on maize. However, extreme heat was excluded.

6.4 Conclusion and recommendations

The economic debate on the impact of climate change caused by the increase in atmospheric CO_2 is centred around the contrast between the positive effects that elevated CO_2 has on the plants and the negative consequences that accompany higher levels of CO_2.

The model that is recommended for any future studies on the topic is the Ricardian model, due to its use of empirical data on real life farms and crops rather than the reliance of simulations. The Ricardian method is used to study agricultural production through a cross sectional approach (Mendelsohn and Dinar, 2003). The method is named after Ricardo who in 1817 observed that land values would reflect land productivity at a site under the conditions of perfect competition (Benhin, 2006: 24). Farm value, therefore, represents the present value of future net productivity. However, the main objective of the research project is to measure the impact of changes in environmental factors (i.e. climate change) on land values and revenue so the study needs to use a reduced form of the Ricardian model to test how a set of endogenous variables affect revenue (Benhin, 2006: 25). It is, therefore recommended that future studies in the research area make use of a revised Ricardian model as the model is able to test the effect on overall revenue by endogenous variables.

Nevertheless, the case study and post-positivist approach adopted by the project concluded that in order to ensure that maize farming is a viable income source, farmers are placed in a situation where they must adapt to the new climate to mitigate the negative consequences whilst also taking advantage of the positive effects. The project looked at these adaptation techniques, the costs the farmers incur and how successful their practices are. The research found that the larger farmers can increase the scale of production as well as their income whilst the smaller farmers are being left behind. The common belief among the farmers interviewed is that the threshold for commercial maize farming to be economically viable (considering the costs of adapting) is around 1000 hectares. Due to the changing climate, the planting window has become much shorter, therefore the farmers who compete in the market are the ones who can afford the machinery that allows them to plant large areas of maize in the shorter windows.

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Appendix

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INFORMED CONSENT DECLARATION

Farmer Questionnaire

Project Title:
The economic impact of climate change on maize production in the Free State, South Africa

Richard Johnson from the Department of Economics and Economic History, Rhodes University has requested my permission to participate in the above-mentioned research project.

The purpose of the research project is to estimate the economic impact of climate change as a direct result of the rising levels of CO_2 in the atmosphere. The focus will be on the overall production of maize in the Free State province of South Africa. Simulating experiments have found that increasing atmospheric CO_2 levels improve the capacity of plants to produce more output. However, the higher concentration of the gas also causes a rise in global surface temperatures, as well as an increase in the frequency of extreme weather events such as drought, which inhibits the production of crops. The economic debate is, therefore, the contrast of the positive effects and the negative consequences.

Rhodes University has given ethical clearance to this research project and I may request to see the clearance certificate.

I will participate in the project by undertaking a questionnaire that will seek to ascertain how the increased levels of CO_2 in the atmosphere has economically impacted maize production on my farm.

I will not be compensated for participating in the research, but my out-of-pocket expenses will be reimbursed.

There may be risks associated with my participation in the project. I am aware that:

a. the following risks are associated with my participation: Embarrassment or reservations due to sharing financial data.
b. the following steps have been taken to prevent the risks: The participant has the opportunity to read the questionnaire in advance to allow for any disputes to be heard before the data is collected. Questions are phrased in such a way that respondents may give a response without feeling like they have inadequate knowledge. Personal details and information will not be published or made available in any of the published work and all stored data will be stored without the personal details of the participants being included. The questionnaire does not require the participant to give their name.

The researcher intends to publish the research results in the form of a master's thesis. However, confidentiality and anonymity of records will be maintained and the identity of the participant will not be revealed to anyone who has not been involved in the conduct of the research.

Participant Information	**Response**
I understand the purpose of the research study and my involvement in it.	Yes/ No
I understand the benefits of participating in this research project.	Yes/ No
I understand that I may withdraw from the research project at any stage without penalty.	Yes/ No
I understand that participation in this study is done on a voluntary basis.	Yes/ No
I understand that while information gained during the study may be published, it will not be identified and my personal results will remain confidential.	Yes/ No
I understand that the researchers would like to record the interview for their own records and am aware that the recording will not be made available to anyone except researchers directly involved in the project.	Yes/ No
I would like an electronic copy of the complete thesis to be emailed to me.	Yes/ No

By signing this informed consent declaration, I am not waiving any legal claims, rights or remedies.

A copy of this informed consent declaration will be given to me, and the original will be kept on record.

I, ... hereby voluntarily consent to participate in the above-mentioned research project.

…………………………………. …………………………………

Participant's signature **Date**

…………………………………. …………………………………

Researcher's signature **Date**

Any queries should be directed to Richard Johnson, available at g15j0048@campus.ru.ac.za or on 076 520 6239.
Any complaints should be directed to the Rhodes University Ethics Coordinator Mr Siyanda Manqele, available at s.manqele@ru.ac.za

Questionnaire

1. What variety/varieties of maize are you currently growing on your land?

____
____
____
____
____
____

2. Does maize production make up a significant portion of your income (i.e. does it constitute 50% or more of your annual income)? Please indicate your answer by circling it

   Yes No

3. Do you cultivate any other crops (please indicate which)?

   Wheat Soybeans Sunflowers

   Other:

   ____

4. Please detail your annual maize production as best you can in the following table (if you were not producing in that year please put "N/A". If estimating, please provide a range, i.e. 20-30 tonnes):

Year	Production (Tonnes)
2015	
2016	
2017	
2018	
2019	

5. In the last production season, what was your turnover from maize (In Rands)?

   ____

6. In your last production season, how many hectares of land did you have under maize production?

   ____

7. What was your cost of production in the last production season?

____

8. On average, would you say your costs of production per hectare, have increased, decreased or stayed the same?

____

Comments:
____

9. Do you have any intention of changing the number of hectares you have under cultivation?

Yes, increase   Yes, decrease   No

10. If yes, why?
____
____
____

11. Higher levels of CO_2 in the atmosphere has been attributed to be one of the main causes of climate change, resulting in more volatile weather conditions, drought and heat, as well as changing rainfall patterns. Which of these have you experienced? (Tick all appropriate boxes)

❑ Heat

❑ Drought

❑ Change in rainfall patterns

❑ Other

____

12. Simulating experiments have suggested that increased CO_2 in the atmosphere has some potential benefits to maize production. Please indicate whether you agree or you make use of any of the changes.

[SD = Strongly disagree, D = Disagree, N = Neutral, A = Agree & SA = Strongly agree**]**

	SD	D	N	A	SA
Improved water use efficiency					
Accelerated growth rates					
Increase in yields					
More lenient planting and harvesting dates					

13. Can you think of any other benefits that are not covered by the above statements? If so, please detail those benefits below.

____
____
____
____

14. Has the changing climate forced you to change your management strategies?

Yes No

15. If yes, which adaptation or mitigation techniques have you employed? (Please indicate your answer/s with a tick)

- ❑ Change in planting dates
- ❑ Change in variety of maize
- ❑ Introduction of or increase in irrigation

Fertiliser

- ❑ More
- ❑ Less
- ❑ Change in Fertiliser
- ❑ Other:

____

Change in planting methods

- ❑ Zero tillage
- ❑ Strip tillage
- ❑ Conventional tillage
- ❑ Other: ____________________

- ❑ Reduction in CO_2 or any other greenhouse gas emissions
- ❑ Other?

____

16. Do you believe the adaptation techniques you have used have worked?

    Yes No

17. If you were to change any practice what would it be and what prevents you from changing?

    ____
    ____
    ____
    ____

18. Are there any comments or suggestions you feel would benefit the research in the future?

    ____
    ____
    ____
    ____