Weather derivatives as a risk management tool for maize farmers in South Africa

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Abstract

This study evaluates the value of rainfall options as a yield risk management tool in order to assess the viability of weather derivatives in the South African agricultural sector.

Recent developments provide the potential of reducing agricultural risk factors through the introduction of derivatives based on weather variables. These instruments seem especially appealing because they are unaffected by asymmetric information and loss adjustment issues.

Monthly rainfall averages combined with maize yield averages over a period of twenty years is used to find correlations between rainfall and yield. Through this discovery, it was possible to assess rainfall options as a risk management tool against yield risk for maize farmers in the water table soil area in the North-Western Free State. The concept, operation, and application of weather derivatives are mainly explained in this article. By weighing the advantages of rainfall options and recommending an option strategy as a yield risk management tool, the viability of using rainfall derivatives to control agricultural production risk in South Africa is assessed.

Although weather derivatives have advantages over conventional insurances, the market for these instruments in South African agriculture is still limited. This is partially explained by the lack of clarity over whether, and to which extent weather derivatives can be used as a risk management tool in agriculture. To assess the risk-reducing benefit that can be obtained in maize production by adopting rainfall choices in South Africa, this study uses maize yield and weather data from North-Western Free State, which is the biggest maize producing province in South Africa (CEC, 2020).

The contract design regulates the efficiency of hedging. . If pre-defined conditions associated with the underlying asset occur, one party (the investor) promises to make a financial commitment to another (the purchaser or contract owner). The writer receives an advance payment in exchange for this promise and the financial risk it entails. However, the farmer is still responsible for the geographical and basis risks. The study makes it possible to draw conclusions on the creation of weather derivatives. The issue raised here is pertinent to both farmers and potential sellers of weather derivatives.

As capital markets, financial institutions, insurance companies, crop insurance companies, and hedge funds organize themselves to share and manage weather risks, the use of rainfall derivatives in South Africa is projected to rise in the future, thus the issue raised is pertinent to both farmers and potential weather derivative traders and underwriters.

Keywords: Weather Derivatives, Maize, Rainfall options, Yield Risk, Crop Insurance, South Africa, Risk management

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List of abbreviations

ALRRD	: Agriculture, Land Reform and Rural Development
CEC	: Crop Estimates Committee
CME	: Chicago Mercantile Exchange
CSA	: Climate-smart Agriculture
EWS	: Early Warning Systems
GDP	: Gross Domestic Product
JSE	: Johannesburg Stocks Exchange
MPCI	: Multi-peril Crop Insurance
NASA	: National Aeronautics and Space Administration
NWU	: North-West University
OTC	: Over-the-counter
SADC	: Southern African Development Community
SAFEX	: South African Futures Exchange
SAGIS	: South African Grain Information Services
SAIA	: South African Insurance Association
US	: United States
VaR	: Value-at-risk
YaR	: Yield-at-risk

Chapter 1

Introduction

1.1. Introduction and background to the study

Risk is an inherent part of agriculture. Farmers have tried to develop ways to make farming less risky by achieving control over the production process, and since the abolishment of the various marketing boards, the marketing process as well. Weather uncertainty is one of the biggest concerns for dryland crop farmers that contribute to yield risk in the agricultural sector. The unpredictability of temperatures and precipitation (both rain and snowfall) has increased the risk due to climate change (Sun *et al.*, 2019).

The impact of weather risks extends beyond crop production in the agricultural production sector, and also influences all the participants in the agricultural value chain. According to Masipa (2017), agriculture production in Southern Africa will decline from twenty-one per cent to nine per cent by the year 2080 due to adverse weather conditions. Masipa (2017) also indicates that two-thirds of high-potential agricultural land in Southern Africa will be lost by 2025 due to extended droughts and the Food and Agricultural Organisation (FAO) estimates that if desertification continue, Africa can lose two-thirds of arable land by 2030 (Bafana, 2017). An ever-increasing global population, diminishing agricultural land and adverse weather due to the effect of increased climate change on agricultural and food production are placing even more emphasis on food security. A report from the World Food Programme (2016) shows that crop production yield grows at a rate that is slower than the rising population. Crop yield improvements have been critical in feeding a growing population even tough food production grows at a faster rate than the global population each year (Maja & Ayano, 2021). Crop yields may appear to be far from one of the world's most pressing issues. However, if yields and labour productivity do not rise, the consequences for global poverty will be severe. This suggests that the world's future food supply will be unlikely to fulfil global food demand. This will soon leave many countries with reduced food security; South Africa is also not immune to these challenges.

In South Africa, farmers receive limited support from the government in the form of subsidies to help manage risks faced in the agriculture sector. The diesel rebate is one of the only government-provided benefits that help farmers and protect them against international competition (Louw, 2018). Governments in the rest of the world support their farmers in varying degrees, as indicated by Figure 1.1.

Country	Producer Support Estimate (% GDP), % of GDP, 2020	Producer Support Estimate (% GFR), % of GFR, 2020	Support based on commodity output, % of GFR, 2020	Payments based on input use, % of GFR, 2020
Japan	0.79	40.9	33.5	0.8
Norway	0.71	50.9	23.1	3.5
China	1.39	12.2	8.5	1.1
OECD	-	18.1	7.2	2.7
European Union	0.59	19.3	3.1	2.9
Russia	0.39	6.7	2.6	2.4
United States	0.2	11	2.5	2.8
South Africa	0.19	2.8	2	0.8
New Zealand	0.1	1	0.8	0.1
Brazil	0.15	1.3	0.6	0.7
Australia	0.06	1.7	0	0.7
Argentina	-2.15	-18.8	-19	0.2

Figure 1.1: Producer support from governments in different countries as a percentage of Gross Farm Receipts
Source: OECD, 2020.

The South African government reduced agricultural support during the mid 1990s. Gross farm receipts have declined from 5% in 2010 to 3% in 2018, and the total agriculture support estimate percentage of GDP was only 0.19% in 2020 (OECD, 2021). Figure 1.1 indicates that South African farmers form part of the bottom five countries that receive the least producer support based on commodity output. When input costs are analysed, it is clear that it is expensive to produce a ton of maize in South Africa, as shown in Figure 1.2.

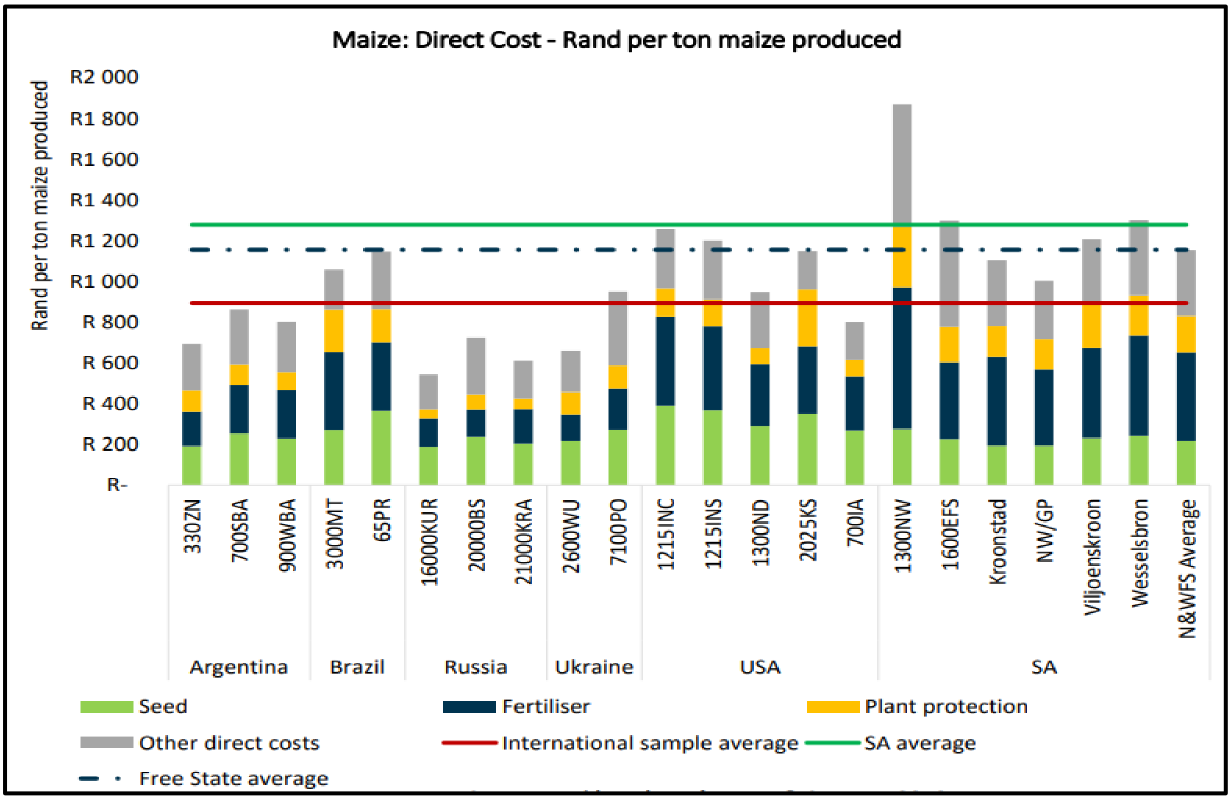

Figure 1.2: The direct cost composition for maize incorporating respective yields
Source: Grain SA, 2020.

According to the Summer Crop Scenario Report published by Grain SA (2020), it is more expensive to produce maize in South Africa compared to the world-leading exporting maize countries. Figure 1.2 indicates the average direct payable cost per ton of maize produced is R894. In South Africa, the cost per ton of maize produced is R1277, which is 43% higher than the global average. In South Africa, the fertiliser cost component is on average 80% higher, owing to a combination of lower yields and higher nutrient costs (Grain SA, 2020). It should be acknowledged that South Africa has high input costs and very minimal government agricultural support. Furthermore, when compared internationally, South Africa has a limitation in terms of climatic (rainfall) factors (Grain SA, 2020). South Africa is one of the countries that receive the least average annual rainfall compared to the highest-producing maize countries (FAO, 2020). Given the low subsidy support from the government and high input costs, the profitability of crop farmers in South Africa is under pressure.

Rainfall is crucial for crop growth and the development of good yields for dryland agriculture. In South Africa, 95.4% of the total amount of maize planted in 2020 was planted on dry land (CEC, 2020). This means that a big part of agriculture in South Africa is vulnerable to the unpredictability of rainfall and is exposed to yield risk. Maize farmers in South Africa, especially dryland maize producers, are dependent on the frequency and the timing of rain for good yields. South Africa can be described as a dry country with an average rainfall of 464mm of rain per year (World Bank Climate Change Knowledge Portal, 2020), compared to the United States, which is the highest-producing country of maize with 767mm of rain per year (National Climate Report – Annual, 2021). Considering the average rainfall in South Africa, the average yield of maize varies from 4t/ha to 6t/ha (Hawkins, 2020). According to Grain SA (2020) and Figure 1.3 and Figure 1.4 below, producers are performing exceptionally well locally when yields are considered in the context of available precipitation per season.

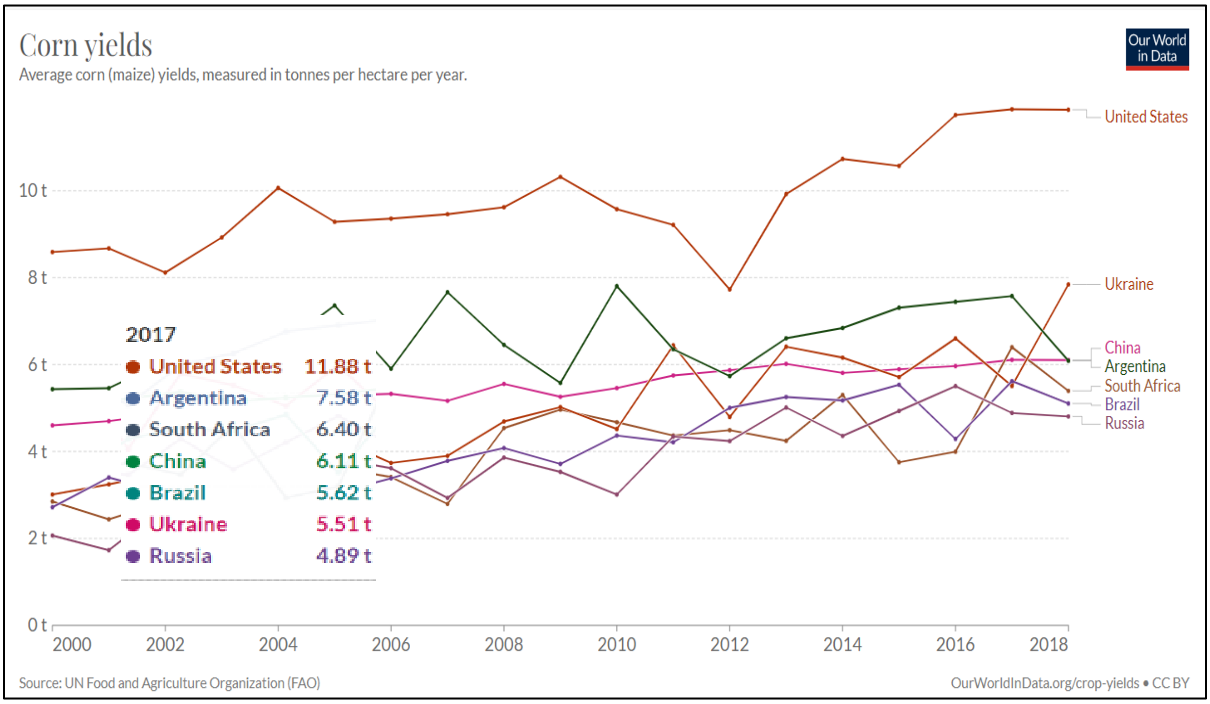

Figure 1.3: South Africa's average annual maize yields compared to top-producing countries
Source: FAO, 2020.

From Figure 1.3 above, one can derive that South African farmers manage to produce 12.9kg of maize for every millimetre received in 2017. The US managed to produce 16.6kg of maize for every millimetre received. Compared to the top maize-producing countries, South Africa's annual average rainfall is low as seen in Figure 1.4, but they compete well on average yield per hectare of maize.

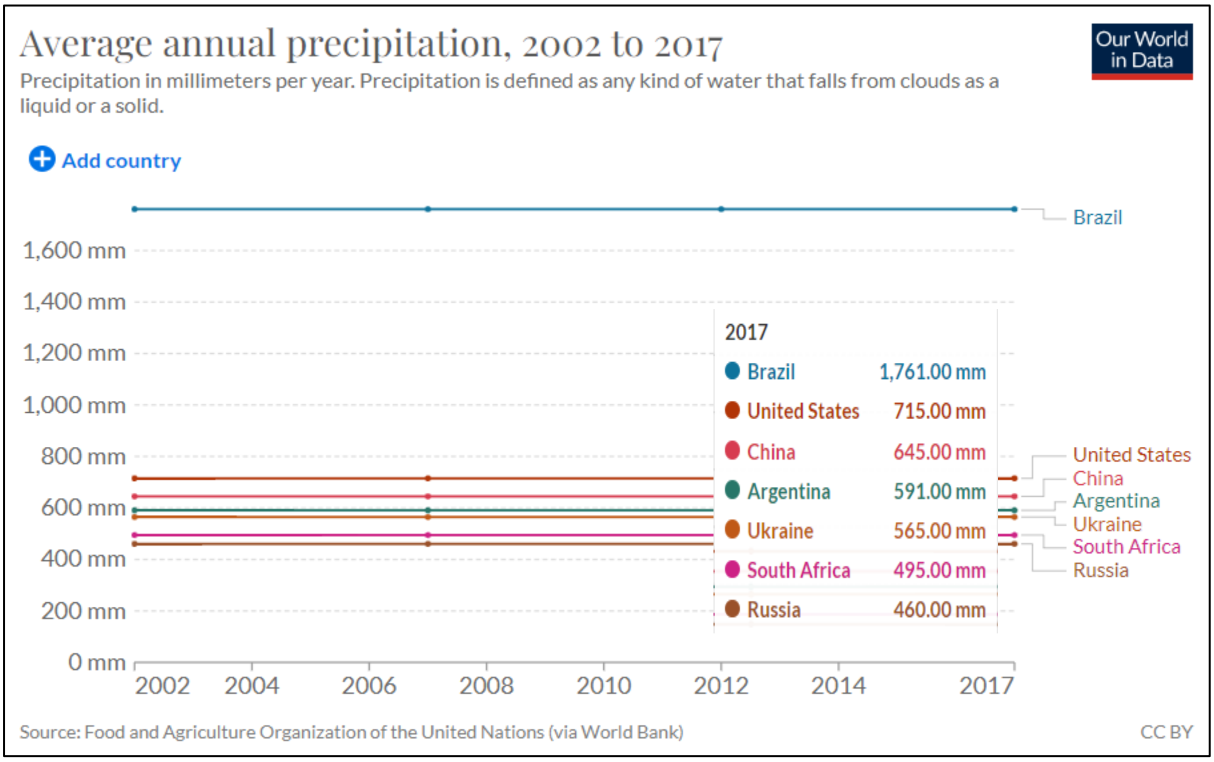

Figure 1.4: South Africa's annual average precipitation compared to top maize countries
Source: FAO, 2020.

South Africa is heavily reliant on agricultural input imports (Campbell, 2020). This means that the same supply and demand forces that regulate international markets influence local prices. South Africa's high reliance on imported inputs for agricultural production exposes the country's agricultural sector to volatility in the macroeconomic environment (Campbell, 2020). It is, therefore, very important to find alternative ways that can help farmers manage not only price risk but also yield risk as well. Yield risk is the unpredictability of the crop growth processes. Weather, disease, pests, and other external factors all have an impact on the quantity and quality of the commodities produced (USDA, 2020). Yield risk varies by region and is affected by soil type, climate and irrigation.

Agriculture is a high-risk sector with actual and persistent threats such as hail, drought, floods, and unavoidable plague outbreaks that can impact yields negatively. Maize is an important animal feed and staple food in South Africa, as well as an export product, with an average of 25% being exported to neighbouring countries (Greyling & Pardey, 2019).

Weather hazards influence a substantial portion of the agribusiness industry. Weather is uncontrollable; thus, it is very important to find different ways to manage yield risk. While there is limited action (except for microclimate management plans, e.g., hothouses) to be done to control weather conditions, producers use insurance products to protect their crops against unfavourable weather.

Multi-peril crop insurance (MPCI) products are available in South Africa (Wiese, 2019). The uptake by farmers is low. In 2019, the MPCI market for crop and harvest-related insurance represented 30% of the value of all crops and with a market penetration of only 17% of planted crops (Wiese, 2019). The South African Insurance Association indicated that premiums are expensive and that farmers struggle to afford MPCI due to the cost-price squeeze experienced in agriculture. According to Xu *et al*. (2008), weather derivatives came as another solution in the mid- 1990s to help mitigate weather risk. Weather derivatives allow farmers to reduce crop production risk without the systemic risk and high admin expenses associated with traditional loss-based crop insurance (Wang, Young Douglas & Zhang, 2013). Although weather derivatives are not commonly used in South Africa, they have the potential and trends in the global market to transfer weather-related crop risks.

Weather cannot be exchanged, which limited the market for weather, and made weather derivatives challenging to explain theoretically (Xu *et al.*, 2008). Weather derivatives are based on the same principles of options, futures and swaps (Geyser & Van der Venter, 2001). Weather derivatives vary from typical derivatives because there is no underlying instrument traded. Weather, unlike equity, bonds, and exchange derivatives, is not traded as an underlying in the spot market (Geyser & Van der Venter, 2001). Weather is unquantifiable and cannot be priced like other derivatives, and weather cannot be used to hedge the price of the underlying. Therefore, proxy weather is used to hedge against other risks that are impacted by the weather, like yield risk in agriculture. Hedging weather can help farmers protect themselves and their businesses from severe costs due to bad and unfavourable weather conditions.

Although the aim of both weather insurance products and weather derivatives is to manage yield risk, there are significant differences between the products. Each product has its characteristics to make one more attractive than the other. Weather insurance contracts cover low-probability, and catastrophic weather events and only pay out when the actual damages are determined by a proper loss adjustment (Stoppa & Hess, 2003); whereas a rainfall derivative is like an option to pay out on the occurrence of nature (Stoppa & Hess, 2003). Payment occurs if the predetermined index value is triggered and a long position holder doesn't need to prove that a loss occurred. Furthermore, because the cost of the weather index is not affected by the individual behaviours of market participants, classic insurance problems such as moral hazard and adverse selection are absent (Sun & van Kooten, 2015).

Weather derivatives are an effective risk management tool that can assist farmers in hedging against weather unpredictability by limiting the downside of traditional insurance, by linking payoffs to measured weather indices. Weather-based derivatives have lately attracted attention as a potential agricultural risk management tool in the literature (Barnett, Barrett & Skees 2008; Barnett & Mahul 2007; Dischel & Barrieu, 2002; Skees & Ayurzana 2002; Martin *et al.*, 2001; Turvey, 2001; Sakurai & Reardon 1997). The majority of these studies have concentrated on the pricing of weather derivatives.

The biggest benefit of weather derivatives over weather insurance is that the compensation is based solely on the value of the weather index at expiration, eliminating the possibility of adverse selection and moral hazard, which are major drawbacks of weather insurance. On the upside, weather options have the potential to provide the buyer of a weather option with theoretically unlimited profit, while the downside risk is limited to the premium paid for the option (Jones, 2007). Basis risk is a concerning factor that affects the hedging process for derivative users (Woodard & Garcia, 2008). Basis risk arises when the price of derivatives does not show the expected trend as the underlying instrument (Geyser, 2004). This occurs as a result of differences in weather conditions at various weather sites across the country. The concern is that weather at a measurement site far from a weather exposure region may not be representative of the exposure. Farmers would simply prefer contracts that are written concerning the amount of rain that is expected to fall on their fields. This is more complicated because the market requires long-term accurate measurement records to assess the value of a weather derivative, and independent parties at these locations do not typically compile measurement records.

Weather derivatives are a relatively new concept compared to other available instruments in the derivatives market and started to trade in 1997 in the US (Jones, 2007). The Chicago Mercantile Exchange (CME) initiated the first exchange-traded, temperature-related weather futures and options on September 22, 1999, to grow the size of the weather derivatives market and eliminate the counter-party credit risk inherent in over-the-counter weather contracts (Jones, 2007). CME contracts enable big and small investors to hedge their weather-related risks with liquid, predefined contracts, while also having access to the best available prices. Insuring against weather fluctuation is common in economies such as the United States; however, it is not commonly used in South Africa and hedging options are very limited. In 2016, Bosveldgraan (BVG), a risk management company, offered a weather-related risk option covering catastrophic events called WeatherInDe (Uys, 2016). WeatherInDe used satellite data supplied by the National Aeronautics and Space Administration (NASA) to price its weather derivatives (Uys, 2016). Weather derivatives have a wide range of applications, can be used in different industries, and are adaptable to changing conditions, which makes them a proactive risk management tool.

A rainfall derivative is a financial instrument used to assess the risks associated with changing rainfall (Leobacher & Ngare, 2011). The contract specifies how payments will be distributed among the parties depending on the present weather conditions during the term of the contract (Leobacher & Ngare, 2011). The settlement value of these weather events is determined by calculating a weather index reflected as a weather-changeable value obtained at a particular location (Dischel & Barrieu, 2002). Weather derivatives trade over-the-counter (OTC), through brokers, and via an exchange. The seller (the writer of the option) of the weather derivative, together with the buyer of the option, will agree in advance on a predetermined index value, which is the strike rate of the option. The seller will pay out the option to the buyer if the option is exercised, otherwise the option will not be exercised, and the loss will be limited to the premium paid.

This paper will focus on rainfall options as a hedging alternative for farmers to mitigate yield risk as it becomes more difficult for farmers to achieve sustainable profit levels given the cost-price-squeeze and variable yields that are yearly realized.

Historical input costs of white maize in the Northern Free State area would be taken into consideration to determine the profits of farmers during the years 2000 to 2021. The profit margins will then be compared to different scenarios during a season to see if farmers can improve their overall financial position by using rainfall options.

1.2. Problem statement

Rainfall has a severe impact on the profitability of crops. Dryland crop farmers have limited measures at their disposal to protect themselves against the unpredictability of rainfall. In South Africa, there are only a few MPCI products available that can help protect against yield risk, but it is very expensive.

Rainfall derivatives are an internationally recognised risk management tool, but South African farmers are slow to utilize them. For farmers to potentially use weather derivatives, the price of the weather derivative is compared to how well the contract performs in reducing yield risk and how well its payoffs are correlated with losses. This study aims to consider the effectiveness of weather derivatives as a risk management tool for maize farmers.

1.3. Theoretical perspective and framework

This study's literature perspective will provide a broad insight into the financial theory of pricing weather derivatives as well as the complexities associated with changing stochastic variables. This study's theory will reframe derivative payoffs calculated by risk probabilities and previously discovered factors that affect derivative prices. Secondary sources, such as previous research studies, journal articles, textbooks, and working papers, will be used to construct the theoretical framework.

1.4. Research questions and objectives

1.4.1 Primary questions

The problem statement above leads to the following research question:

Are rainfall options financially feasible to reduce yield risk for South African maize farmers?

1.4.2 Theoretical objectives

The following theoretical objectives have been formulated:

- Discuss the development of rainfall derivatives worldwide and the application thereof in South Africa.
- The development of MPCI's in South Africa.
- Discuss different hedging opportunities for farmers to protect against yield risk.

1.4.3 Empirical objectives

The empirical portion of the study includes the following objectives to help with the accomplishment of the primary research questions:

- Determine the maize yield-at-risk relationship with rainfall.
- Determine an average rainfall index for the growing period of white maize in the North-Western Free State.
- Determine profit margins with historical input costs of white maize.
- Determine the potential cost of a rainfall derivative.
- Determine the financial feasibility of a rainfall derivative for maize farmers in South Africa.

1.5. Research design and methodology

This research study includes a literature review, a theoretical and empirical study, and an explanation of how the research was designed and the methodology used.

1.5.1 Study design and context

Secondary statistical data will be used to inform this quantitative study. Welman and Kruger (1999) define secondary data as information gathered by institutions or individuals other than the researcher. Data will be collected from various institutions.

1.5.2 Empirical study

The empirical component of this research study will begin with the collection of data from various sources, such as The South African Weather Service, Senwes, Grain SA and the Johannesburg Stock Exchange (JSE). Historical data from these sources will then be used to run the models explained below. Historical rainfall records will be obtained from the South African Weather Service and Senwes; historical yields will be obtained from) Crop Estimates Committee; spot prices of maize will be obtained from the JSE; and historical input costs will be obtained from Grain SA.

The first step would be to determine the ideal amount of rainfall that would lead to profitable yields and a good harvest by using the concept of yield-at-risk. After that, the price of the option can be determined through the different existing models discussed below. A sensitivity analysis, according to the profitability of the farm, will then be done to determine if the farmer would be in a better financial position if he had taken out a rainfall option.

The different models will help determine if rainfall options are financially feasible with the cost of the premium compared to their specific financial scenario.

1.5.3 Secondary data

1.5.3.1 Model

The option price for rainfall derivatives will be divided into two options, namely a call option and a put option.

$$P_{call} = k \times \max(S - I_t, 0) \tag{1.1}$$

Where

- k is the pre-agreed constant factor that determines the payment unit of the weather index
- S is the strike rate
- I_t is the weather index

A call option is a contract where the buyer and the seller pre-agree on a contract period and the weather index (I_t) for the basis of the contract. The seller will receive a premium from the buyer at the beginning of the contract. If I_t is greater than the pre-agreed strike (S) during or at the end of the contract, the option will realise, and the seller pays the buyer.

$$P_{put} = k \times \max(S - I_t, 0) \tag{1.2}$$

A put option is similar to a call option contract in that the seller pays the buyer when I_t is less than S.

With a call and a put contract, the buyer must pay a premium to receive compensation when pre-agreed conditions are met (Geyser, 2004). The price of the option is calculated from the payoff expected to be received.

$$c = \exp\big(-r\,(T - t)\big)\,P \tag{1.3}$$

Where

- c is the premium buyers need to pay
- r is the risk-free market interest rate
- T is the maturity or expiration date of the contract
- t is the date when the contract is issued
- P is the payoff based on the predicted rainfall

1.5.3.2 Data sources

The study will make use of published data obtained from the JSE, the South African Weather Services, SAGIS, Grain SA and Senwes. The data set consists of historical data for the period 2000 to 2021, which contains rainfall, maize spot prices, input costs, interest rates and yields for white maize in the North-Western Free State. The risk-free market interest rate (r) will be obtained from the South African Reserve Bank. The data will be processed in monthly intervals corresponding to the maize growing season, which runs from November to March. Where possible, the models will be tested on daily, weekly and/or monthly data to test for robustness.

1.5.3.3 Econometric methods of analysis

The historical data will initially be compiled into one Excel file, converted to different frequencies and then exported to EViews 12 for further analysis.

Relevant descriptive statistics, correlations and multi-linear regression analysis will be performed in EViews 12 to establish if there are statistically significant relationships.

1.6. Expected possible outcomes

Rainfall and yields are positively correlated up until a certain point. If the maize receives too much rain in a short period, it can harm the yield. Conversely, if too little rain is received during the critical stages of maize production, it also has a negative impact on yield. If too much rain or droughts occurs over the whole country during a specific period, it will be assumed that spot prices of white maize will be higher due to market reactions.

By developing this tool and making it more accessible, farmers can improve their yield risk management. This research has the potential to help farmers improve yield risk management, which can help them make better-informed decisions regarding financial management.

The assumption will be made that farmers who make use of options to hedge themselves against yield risk will be in a better financial position than those who do not hedge.

1.7. Ethical considerations

This study poses little risk as it relies on secondary data. As a consequence, no individuals or vulnerable groups will be implicated or associated with this research. This research study adhered to the North-West University's ethical guidelines and principles (NWU, 2016:15).

1.8. Chapter classification

Chapter 1: Introduction

The first chapter of the study identified and subsequently elaborated upon the introductory subjects leading to the study. It provided the map for the study by outlining the background of the study, the problem statement and research objectives of the study, and both theoretical and empirical objectives. Research design and methodology, societal and ethical considerations, and limitations of the study were also discussed, and the chapter concluded by providing the outline of the research chapters.

Chapter 2: Literature review

Chapter 2 will begin by providing a literature review of the importance of agriculture in South Africa. It will also give an in-depth look at the sensitivity of maize yields concerning optimal rainfall during critical stages of the maize plant. The extreme changes in weather patterns in the past two decades and how these influence hedging tactics, will also be viewed. The chapter will also focus on the low-profit margins achieved by maize farmers during periods of adverse rainfall. The chapter will discuss the development of rainfall derivatives worldwide and the application thereof in South Africa. Available insurance products to manage yield risk will also be discussed.

Chapter 3: Research design and methodology

The third chapter will concentrate on the empirical study. The empirical portion of this study will be conducted using a quantitative research method. Secondary data will be obtained from the South African Weather Service, SAGIS, Grain SA, Senwes, and the Johannesburg Stock

Exchange. The data will be transferred to Excel before being imported into EViews 12. EViews will perform relevant descriptive statistics, correlations, and multi-linear regression analysis to determine whether there are statistically significant relationships.

Chapter 4: Results and findings

The primary goal of this chapter will be to analyse the results. The empirical findings will be presented in this chapter. The findings will be thoroughly discussed to determine whether there is a relationship between yield and rainfall, and to determine and price a rainfall option.

Chapter 5: Conclusions and Recommendations

Chapter five is the final chapter of this dissertation, and it serves as the dissertation's conclusion. It accomplishes this by referring to both the problem statement and the results to form a compelling study conclusion. Recommendations for additional research on this topic will also be made.

Chapter 2

Literature Review

2.1 Introduction

Globally, the world is troubled with uncertainty and the market environment is constantly changing. Crop growth and yields are sensitive to weather conditions. This is especially true for rain-fed crops. It will be beneficial if producers can implement a strategy to mitigate the risk of uncontrollable weather.

In this chapter, the main objective is to look at different factors that affect maize yield and production in South Africa. In-depth literature studies will evaluate the different characteristics of the maize market in South Africa and the effect of climate change on producers' decisions to mitigate risk. It will also evaluate the sensitivity of maize yields concerning optimal rainfall during critical stages of the maize plant.

With this in mind, the chapter will focus on the low-profit margins achieved by maize farmers during periods of adverse rainfall. Thereafter, different insurance products available to farmers to mitigate yield risk will be discussed. The chapter will end with an examination of weather derivatives and their application in South Africa.

2.2 The importance of agriculture in South Africa

Agriculture is a diversified, complex and volatile market (Moore, 2021). Volatility is primarily caused by supply constraints (Uys, 2016). Weather and food production quality can also significantly impact price development, especially when supply availability is uncertain. The industry's complexity is high because there are many different variables affecting the sector.

The agricultural industry is an industry that has changed in many ways over different decades. Farming profitability has declined, and water scarcity (drought, declining rainfall, or over-demand for water) has reduced South Africa's farm population to less than two-thirds of what it was in the early 1990s (Kotze & Rose, 2015). Many farms have been consolidated into larger farming units to achieve effective economies of scale. Domestic production has increased and improved over the years. The enhancements in yields can be attributed to the expanded number of hectares planted, genetically modified seeds, fertilizers being used when planting and better farming practices (Kotze & Rose, 2015). Farmers can work larger areas of land with less labour, thanks to new technology and larger farm machinery.

The constantly changing environment makes it hard to make good economic decisions, especially for crop farmers. Farmers have to keep up with new technology, new farming practices, and products constantly improving, like new cultivars. This is expensive to keep up financially. Even though South African agriculture experienced vast technological improvements and improved management practices, South African farmers still face an increasing cost price squeeze (Blaker, 2021) and ways to reduce risk are necessary.

South African agriculture produces a wide variety of grains, cereals, fruits and vegetables. Nearly all crops are exposed to different environmental factors, which influence production. South Africa's agricultural sector expanded by 8.3% in 2021, well above the BFAP's baseline projection of 7.6% in August 2021, and the second consecutive year of strong performance after 13.4% growth in 2020. Despite higher input prices, BFAP forecasts a 5% increase in South African real agricultural GDP in 2022 (BFAP, 2022). An estimated 20 per cent of South Africa's farms supply 80 per cent of food in the formal retail chain (Cousins, 2015). According to the Minister of Economic Development, commercial farmers produce 95 per cent of the country's food (Kotze & Rose, 2015). The industry generates a large number of jobs for the country's largely unskilled labour force. According to Agriculture, Land Reform and Rural Development (ALRRD), Minister Thoko Didiza, agriculture employment increased by three per cent to 829 000 in the third quarter of 2021, exceeding the long-term agricultural employment figure of 780 000 (Engel, 2021).

Role players in this sector have to improve the safety of food in the food value chain as people become more aware of what they eat and the environmental impact (Moore, 2021). Despite these complexities, agriculture is widely expected to be a key driver of economic growth, both locally and globally (Moore, 2021). Agriculture and food value chain sectors remain strong outliers in a troubled global economy, driven by population growth.

Agriculture is also very important for different economies and economic growth around the globe, especially in developing countries. According to the World Bank (2022), in 2018, agriculture accounted for four per cent of the global GDP, and in some least-developed countries, it can account for more than 25 per cent of the GDP. South Africa forms part of a developing economy and it is important to prioritise a healthy agriculture sector to contribute to the country’s GDP, food security and employment.

The South African agricultural sector outperformed the other sectors during the Covid-19 pandemic. The agricultural sector was the sector with the highest growth rate in GDP in the fourth quarter of 2021 (Stats SA, 2022). Figure 2.1 shows how important the agriculture sector is for economic drive and GDP growth in South Africa.

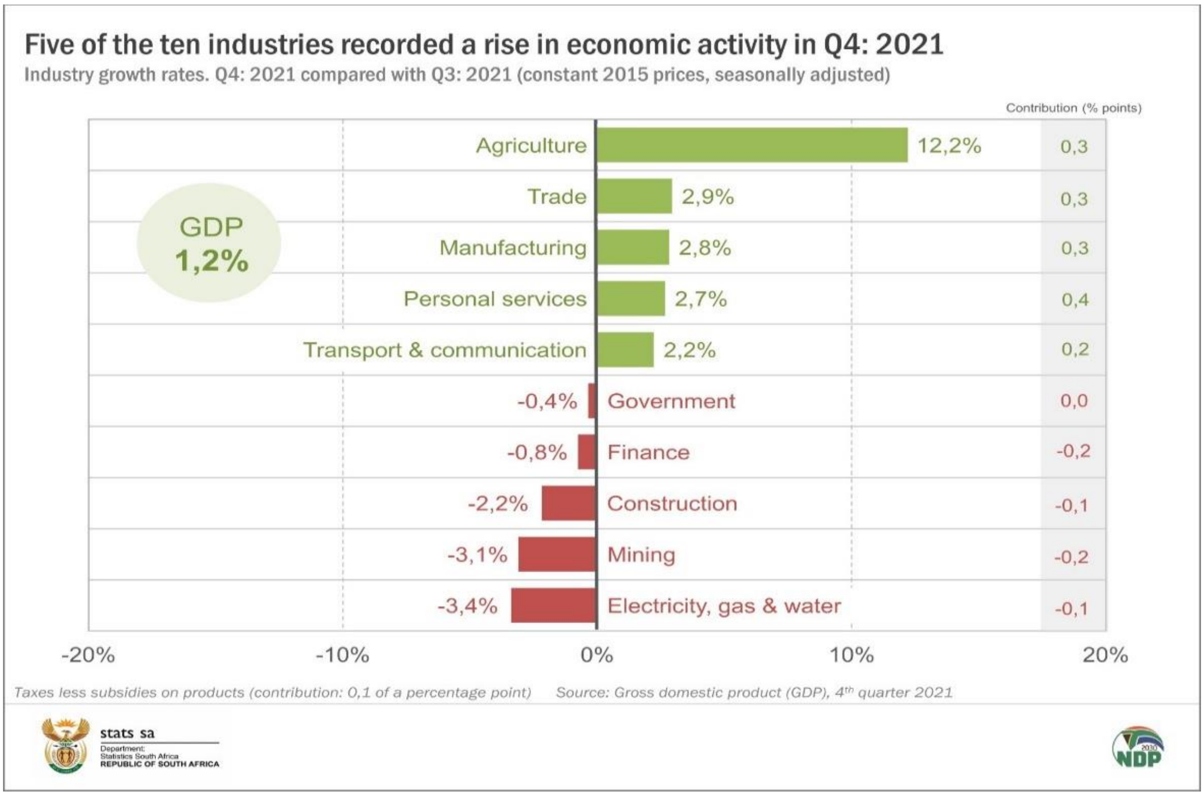

Figure 2.1: Industry growth rates in South Africa during the fourth quarter of 2021
Source: Stats SA, 2022

The sector's good performance in 2021 with growth in all four quarters stood out compared to the other sectors. According to Stats SA (2022), agriculture contributed 5.9 per cent growth in agricultural GDP, which was 13.1 per cent in the overall GDP growth. The high levels of agricultural output can be attributed to favourable production conditions (due to a La Nina weather pattern), high commodity prices, strong export demand, and a favourable rand exchange rate that bolstered this outperformance (Moore, 2021). The industry was also labelled as an essential service, which was allowed to continue operating during the lockdowns.

The whole nation is dependent on the agricultural sector for food. Agriculture provides income and employment for approximately 70 per cent of the country's population (SADC, 2020). Agriculture contributes thirteen per cent to total export earnings and 66 per cent to the value of intra-regional trade of the Southern African Development Community (SADC), indicating that it is a centrepiece of the economy in these member countries (SADC, 2020). As a result, the performance of this sector has a significant impact on Africa's food security, economic growth, and social stability.

Maize is the main crop produced in South Africa; between 1970 and 2015, an average of 57 per cent of commercial field cropland was dedicated to maize production (Greyling & Pardey, 2019). The sector is highly dependent on rainfall, with irrigation agriculture accounting for less than 5 per cent of the country's total white maize production (CEC, 2020). The amount and timing of rainfall during the growing season are critical to crop yields (Camberlin and Okoola, 2003). Rainfall is one of the most important factors influencing agriculture in most semi-arid regions of southern Africa, as soil water availability has a significant impact on crop growth and development (Mukhala, 1998). This limiting factor over South Africa's Free State Province, which is the biggest producing province (CEC, 2020), is largely caused by unreliable seasonal rainfall and high variability in the onset and cessation of rains.

The starting of the agricultural season in most parts of South Africa will be when the rain starts to fall after the last frost date (Moeletsi *et al.,* 2011). The timing of the onset of rains can have a significant impact on agricultural productivity, with late onsets frequently resulting in lower yields (Camberlin and Okoola, 2003). The late onset of rains can cause a shorter growing season affecting the productivity of medium or long-season maize cultivars. The late onset of rain forces farmers, due to the time limit, to plant short-season varieties, which have lower yield potential than the planting of medium to long-season maize cultivars (Moeletsi *et al.,* 2011). Rainfall variability, unreliable occurrences, insufficient amount, and delay in onset dates all contribute to a decline in crop yields in almost all parts of the country. Rainfall variability jeopardizes food security. During the 2015/16 drought, crop production was reduced by 50 per cent compared to the five-year average, and crop yields decrease by 20–50 per cent in extreme El Niño years (Sazib *et al,* 2020).

The variation in rainfall has a significant impact on the income of every household whose livelihood is dependent on agriculture, independent of whether you are a producer or a consumer. The variability reduces incomes, which reduces demand for goods and services in affected communities. According to Nhemachena *et al.* (2009), rainfall variability and higher average temperatures harm African households' income from crops and livestock. Shumetie *et al.* (2017) investigated the impact of climate variability on smallholder crop income and concluded that rainfall variability during the cropping season has a significant and negative impact on farmers' crop income.

Dell, Jones, and Olken (2008) demonstrate that climatic variability has a significant and negative impact on economic growth in developing countries. Since developing countries have a greater proportion of their GDP in climatically sensitive sectors, their economic resources are vulnerable to climate change. It may reduce output and the economy's potential productivity growth by reducing agricultural production and exports (Jones & Olken, 2010).

Climate change has an impact on food security by having a large negative impact on food prices. Because food is a basic necessity good with high price inelastic demand, a decrease in food surplus may result in a significant increase in food prices, reducing food accessibility.

Ringler *et al*. (2010) use a theoretical model to show that climatic variability increases childhood malnutrition in Sub-Saharan Africa by increasing food prices. Furthermore, Aker (2010) believes that climatic variability may influence traders' entry and exit decisions in response to the profitability of food trading. Indeed, climatic variability that increases (or decreases) profits may prompt traders to enter or exit the local market. Since markets are not well integrated and food price dispersion is high in developing countries (Aker 2010; Araujo *et al*., 2005), climatic shocks may intensify them and harm food security.

2.3 Climate change and agriculture

Climate change is the long-term changes in temperature and weather patterns. These changes could be natural, such as variations in the solar cycle. Humans are causing rapid climate change by using oil, gas, and coal in their homes, factories, and transportation. When these fossil fuels are burned, they emit greenhouse gases, primarily carbon dioxide (CO2). These gases trap the sun’s heat, raising the planet's temperature (BBC, 2021). Rising climate variability increases the risks in agriculture production and prices (Elum *et al.,* 2018). Weather is a key factor influencing economies all over the world, having a significant impact on either business revenues and costs, or both. According to Ivana *et al*. (2016), weather affects four-fifths of the world economy, either directly or indirectly.

According to Aydinalp and Cresser (2008), climate change has a different impact on everyone in agriculture, some benefit from increases in production, while others will experience decreases. Benhin (2006) believed that increases in climate variables, particularly precipitation, will benefit crop farming, but beyond a certain point, the effects will be negative on production. Poonyth *et al*. (2002) examine the agricultural sectors in South Africa’s performance concerning climate change using a Ricardian model and conclude that rising temperatures will be detrimental to agriculture, and the effects will be exacerbated if farmers do not adapt appropriately.

Weather sensitivity is defined as the sensitivity of sales, production, or costs to meteorological elements, such as temperature, sunshine, rainfall, frost, snowfall, wind, etc. If a sector's output volatility is caused by changes in weather, the sector is said to be weather-sensitive. Climate change impacts are primarily felt by those whose livelihoods rely on land and resources (Stringer *et al*., 2009). Agriculture is more exposed, as 95% of agriculture in Southern Africa is rainfed (Nhamo *et al.,* 2019).

Weather can be classified as catastrophic or non-catastrophic, dependent on the seriousness of its impact. Floods (like the 2022 floods in KwaZulu-Natal), hurricanes, tornadoes, and windstorms are examples of catastrophic weather events that can occur but cause massive financial damage. Non-catastrophic weather refers to minor irregular weather, such as a warmer-than-usual winter and a cooler-than-usual summer. The main distinction is that non-catastrophic weather affects a business's profitability but does not endanger lives or property. Uncertainty in future income caused by seasonal differences in average, i.e., normal weather, is referred to as non-catastrophic weather risk (Brockett *et al*., 2005).

Climate change has demonstrated that weather does not have to be extreme to have a significant financial impact on production (Berlage, 2013). Variable weather and climate change cause yield fluctuations, which affect local and global supply dynamics. As a result, volatility in volume and crop prices increase (Kornher & Kalkuhl, 2013). These variations can harm a business' net income. To face these risks and attract financing, it is necessary to reduce the likelihood of such happenings. Weather insurance is a common tool for protecting against extreme weather events; however, it has limitations when it comes to non-catastrophic weather[1]. Weather derivatives[2] represent a new tool for non-catastrophic weather risk management, with numerous advantages over alternative management tools.

Unpredictable weather events are expected to increase in the Southern Africa region, which is overwhelmed by frequent drought occurrences due to its characteristic low rainfall index and variability (Rakgase and Norris, 2015, Stringer *et al*., 2009), and most notably, South Africa is classified as a dry country with an average precipitation of less than 500 mm per year (Botai *et al.,* 2018). Irrigation is used for only 1% of the cultivated area for maize production (CEC, 2020); there is a particularly high reliance on rainfall and thus vulnerability to changing rainfall patterns and amounts.

According to climate models, the maize-growing region should expect a temperature increase of about 1.5°C at the coast and 2-3°C inland by 2100 (IDB, 2020). Regional crop models predict that maize yields will fall by up to 25% compared to the 2009 baseline (IDB, 2020). However, regions with current temperatures that are marginally too low for maize ripening may see increased yields in the mid-term if temperatures rise by up to 1°C. While small pockets of South Africa may benefit from climate change in the country's east, production in the country's west and centre is likely to become more difficult. According to the study by Du Toit *et al*. (2002), crop production in South Africa will become more marginal in the dry western areas, while crop production may increase slightly in the high-potential eastern areas.

Farmers must adapt to the changing environment and respond in cooperation with local authorities. It is important to manage the synergies between adaptation and mitigation by

[1] See Section 2.5 for an in-depth discussion of insurance products available to mitigate yield risk in South Africa
[2] See Section 2.6 for a discussion on weather derivatives

identifying climate-resilient land uses and encouraging the development of climate-smart agricultural (CSA) practices.

CSA is a strategy for guiding actions to transform agri-food systems toward more environmentally friendly and climate-resilient practices (FAO, 2021). Mulching, intercropping, conservation agriculture, crop rotation, integrated crop-livestock management, agroforestry, improved grazing, and improved water management are examples of climate-smart agriculture techniques, as are innovative practices such as better weather forecasting, more resilient food crops, and risk insurance. The overall negative impacts of climate change on production, incomes and well-being can be avoided with CSA practices in tandem with improved weather, early warning systems (EWS) and disaster risk management approaches.

These initiatives are good examples that highlight how information services and CSA increase farmers' climate resilience, and they also show how they enable farmers to make informed decisions, manage risk, take advantage of favourable climate conditions, and adapt to change. CSA can only serve as a tool, and it does not necessarily mitigate yield risk; therefore, it is necessary to look at alternatives that will help farmers better manage yield risk.

2.4 Maize in South Africa

Maize is a warm-weather crop that emerged in central Mexico about 7000 years ago from a widely cultivated grass called teosinte (Drury, 2019). Maize was first introduced to South Africa in 1655 and is now a staple food for human consumption and livestock feed (Sihlobo, 2018). The goal of growing this cereal crop is to achieve high yields. It is a major grain crop in South Africa and can be grown in a variety of environmental conditions.

2.4.1 Maize production in South Africa

Maize planting dates in South Africa are dependable on the onset of rain. It differs from location to location, but planting can start from October to early January (Moeletsi, 2017). Depending on the cultivar, maize needs 120 to 140 frost-free days to reach maturity (Moeletsi, 2010). The growing period can be as long as 160 to 180 days, depending on the region and cultivar. Maize can be harvested when it is dry, and when the kernels have reached a moisture level of 14 per cent (Moeletsi, 2010). Some storage facilities (on and off-farm) have the capacity to dry maize seed to the desired moisture level of 14 per cent Environmental and climatic conditions during the crop's growing period have a direct impact on plant growth and development, and thus ultimately affect crop yield (Moeletsi, 2017). Though maize is grown throughout South Africa, a few provinces, including the Free State, Mpumalanga, and the North-West, compensated for 84 per cent of the country's total maize production in 2020-2021. The Free State province alone produces more than 45 per cent of South Africa's maize (CEC, 2020).

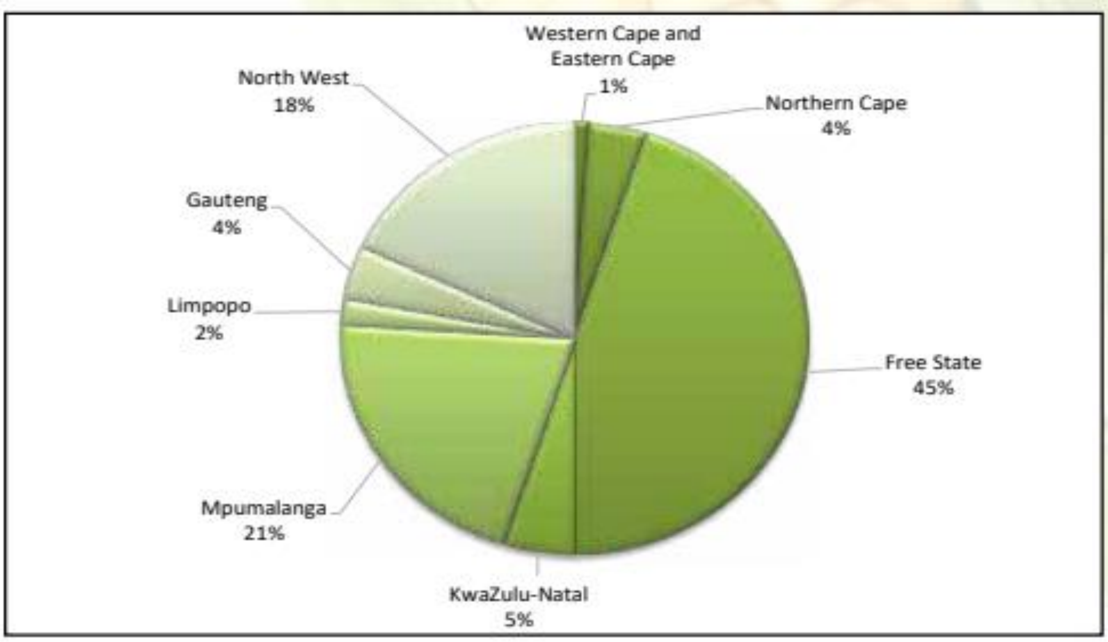

Figure 2.2: Maize crop production contribution per province 2020/2021
Source: CEC, 2020

Production of maize in South Africa has changed a lot over the years. The final maize crop for the 2020/21 season was 16,95 million tons (CEC, 2021). This represents a 7 per cent increase year on year (with the 2019/20 season showing a 35.7 per cent increase year on year) and is 26 per cent higher than the previous 10-year crop average (13,43 million tons). White maize contributed 55.9 per cent to total production, while yellow maize contributed 44.1 per cent.

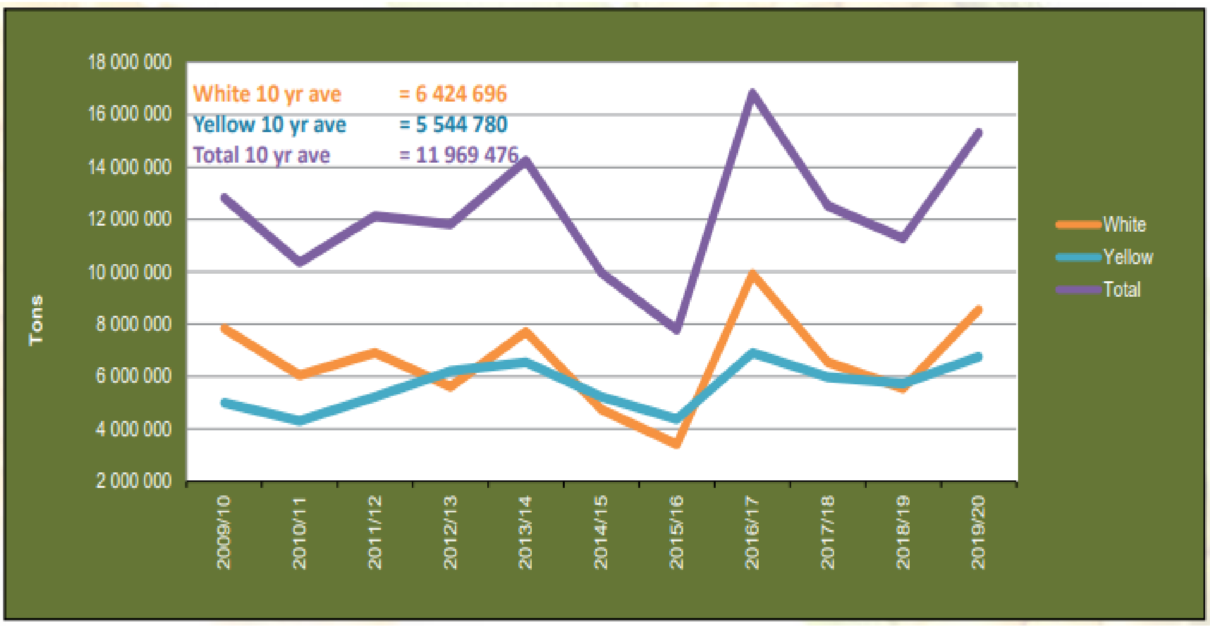

Figure 2.3: *White and yellow maize production in South Africa from 2009/10 to 2019/20*
Source: SAGL, 2020

The total production area is 3.8–4.8 million hectares, 25 per cent of the country's arable land (IDB, 2020). There were 40 122 commercial farmers in 2017 in South Africa and they contributed R332,8 billion to the national economy (Stats SA, 2020). The 10-year average yield is 4.75 t/ha for maize in South Africa (SAGL, 2020). White maize yielded 4.36 t/ha and yellow maize 5.28 t/ha on average over 10 years (SAGL, 2020). White maize is primarily used for human consumption as maize meal, while yellow maize is used for animal feed and food supplements (IDB, 2020). An estimated 86 per cent of maize production is based on a genetically modified seed that has been selected for local climate and soil conditions (IDB, 2020). South Africa's maize production has recently increased. Maize production increased by 6 per cent during the 2020–2021 cropping season compared to the previous season (CEC, 2020). South Africa is one of the world's top ten maize-producing countries (Landman *et al., 2017)*. The actual number for the commercial maize crop for the 2020/21 season, as overseen by the National Crop Estimates Liaison Committee (CELC), was 16 315 million tons (SAGL, 2021).

2.4.2 Maize planting conditions

Low maize yields can be caused by a variety of factors, including limited production inputs, environmental conditions, and management. Following good production practices is the foundation for increasing yields. Applying the recommended fertilizer rates, applying agrochemicals at the correct rates, and planting at an appropriate seeding rate are all good agronomic practices that can be used to increase maize yield (Du Plessis, 2003).

Inputs, rainfall distribution, and heat units are limiting factors in achieving high maize yields. Heat units are calculated by subtracting the daily average of the highest and lowest temperatures from the base temperature, which is 10 °C for maize, accumulated over the growing season (Mbotho, 2018). Depending on the maturity class, maize requires approximately 750 heating units per growing season and 120–140 frost-free days (Mbotho, 2018). As a result, planting should not begin too early, especially in areas where average spring temperatures are less than 15 °C, nor too late, such as between January and February, when the growing season is shortened because heating units begin to drop before the plants reach grain-fill. The average decline in maize production after the optimum planting date for an area is reached, is estimated to be as high as 50 kg/day for the first four to six weeks (Santam, 2016). Although the minimum temperature for germination is 10 °C, germination will be faster and less variable at soil temperatures ranging from 16 to 18 °C (Du Plessis, 2003). Soil temperatures warmer than 20 °C can result in even seedling emergence within five to seven days (Mbotho, 2018). Late planting can use ultra-quick and quick maize cultivars, but higher plant populations are required to compensate for low yields.

The optimal planting time varies by location and is determined by soil temperature and moisture levels that have reached the threshold level for uniform seedling emergence

(Mbotho, 2018). Planting crops during the recommended optimum period for an area will result in the highest yields. Planting at the recommended planting dates for an area ensures that the most favourable climatic conditions occur between planting and physiological maturity.

The planting season for maize in South Africa runs from late October to mid-December. By December 16th, all the seeds should be in the ground (Du Plessis, 2003). This allows plants to survive in January, when extreme heat and low rainfall put plants to the test, allowing them to grow to full size before the winter frosts arrive in late April.

Maize can be grown in areas that receive more than 350 mm of rain per year; ideally between 450 and 600 mm (IDB, 2020). Maize produces approximately 15.0 kg of grain for every millimetre of water consumed and each plant will consume 250 litres of water by the time it reaches maturity (Du Plessis, 2003; OBASF, 2017).

2.4.3 Maize profitability analysis

Profitability, price risk, and crop planning have all become major concerns for farmers. Farmers face industry challenges such as lower profits due to rising input costs and the cost-price squeeze making it important for farmers to understand the principles of price risk.

Costs are also not constant, and it is expected to increase in the new upcoming season. Many factors are at work behind these sharp input cost increases, including supply constraints in key fertiliser-producing countries, primarily China, India, the United States, Russia, and Canada. Rising shipping costs, oil and gas prices, and stronger global demand from expanding global agriculture are all factors contributing to price increases. The ongoing conflict between Russia and Ukraine has intensified the upward price pressures on agricultural input costs (Sihlobo, 2022). South Africa is affected by global developments because it imports approximately 80 per cent of its annual fertiliser consumption and is a minor player internationally, accounting for only 0.5 per cent of total global consumption (Sihlobo, 2022). Crude oil prices and exchange rate fluctuations also have an impact on agricultural market volatility (Uys, 2016). As a result, developments in the major producing and consuming countries mentioned above tend to influence local prices.

As a result, while farmers look for ways to remain profitable, they must also be aware of the long-term challenge of price risk in the surplus production of different crops that can put prices under pressure. Maize is the perfect example if we compare different seasons' supply and demand towards the ending stock of maize. The average domestic demand for maize is around 10,5 million tons a year, but the country produced a total of 16,7 million tons in the 2017/2018 marketing year (Grain SA, 2018). During the same period, the average price for local maize was R1 904,55, compared to R3 587,81 in the 2016/2017 marketing year, when total maize production was 7.7 million tons (Grain SA, 2018). The surplus production of maize caused, amongst others, prices to fall by 88 per cent between the two seasons.

In this literature, we will focus on the profitability analysis of dryland maize in the North-Western Free State, which will serve as the focus area of this research. The Free State is the highest-producing area in the country and produced 6 991 100 tons of maize during the 2020/21 season (Grain SA, 2022) (as mentioned in section 2.2). Table 2.1 gives a breakdown of the various cost components and income potential of maize produced in the North-Western Free State over various yields.

Table 2.1: Income and Cost budget for maize in the North-Western Free State 2021/2022

NORTH WEST FREE STATE INCOME & COST BUDGETS – SUMMER CROPS 2021/22						
CROP		Maize (Lower yield)		Maize (Higher yield)		Maize (Bt)
1) INCOME						
YIELD TARGET (TON/HA)		3.50		6.50		4.50
SAFEX: ESTIMATED PRICE	R	3 150.00	R	3 150.00	R	3 150.00
DEDUCTIONS	R	340.00	R	340.00	R	340.00
NET FARM GATE PRICE	R	2 810.00	R	2 810.00	R	2 810.00
GROSS INCOME (R/HA)	R	9 835.00	R	18 265.00	R	12 645.00
2) VARIABLE EXPENDITURES						
SEED	R	914.40	R	1 457.33	R	1 300.01
FERTILISER	R	2 494.45	R	4 632.55	R	3 207.15
LIME	R	163.17	R	163.17	R	163.17
FUEL	R	1 089.37	R	1 081.91	R	1 121.52
REPARATION	R	782.41	R	806.28	R	790.37
HERBICIDE	R	844.42	R	854.50	R	795.74
PEST CONTROL	R	226.14	R	226.14	R	115.14
INPUT INSURANCE	R	191.78	R	356.17	R	246.58
IRRIGATION COST						
GRAIN HEDGING	R	770.14	R	1 112.96	R	894.78
CONTRACT HARVESTING	R	-	R	-	R	-
HARVEST INSURANCE	R	274.84	R	510.42	R	371.04
AERIAL SPRAY	R	-	R	-	R	-
CASUAL LABOUR	R	-	R	-	R	-
DRYING COST	R	-	R	-	R	-
PACKAGING AND PACKAGING MATERIAL	R	-	R	-	R	-
INTEREST ON PRODUCTION R/HA	R	329.42	R	476.06	R	382.73
TOTAL VARIABLE EXPENDITURE (R/HA)	R	8 080.56	R	11 677.48	R	9 388.21
TOTAL FIXED COST (R/HA)	R	2 914.55	R	2 789.71	R	2 947.72
TOTAL COST (R/HA)	R	10 995.11	R	14 467.19	R	12 335.93
3) GROSS MARGIN (R/HA)	R	1 754.44	R	6 587.52	R	3 256.79
4) NETT MARGIN (R/HA)	R	-1 160.11	R	3 797.81	R	309.07

Source: Grain SA, 2022

According to Table 2.1, the higher the yield the more profitable the maize, areas with higher yields are therefore preferred. A high-potential maize producing area is the water table soil in the North-Western Free State area. Table 2.2 indicates a possible income potential for the North-Western Free State.

Table 2.2: Farm gate maize price

MAIZE	
Average Yield (t/ha)	**6.50**
SAFEX Jul'22 WM 1 price (R/ton)	R 3 150.00
Deductions	R 340.00
Producer price – farm gate price (R/ton)	**R 2 810.00**

Source: Grain SA, 2022

Table 2.2 summarise the farm gate price of high-potential maize in the North-Western Free State. The higher maize yield of 6.5t/ha was used because this area is known for its water table soil providing higher potential and better yields. The deductions of R340.00 includes location differentials and marketing costs. Take note that maize prices differ daily, the SAFEX Jul'22 WM1 of R3150 was used to set up the table. Prices are affected daily by different variables like the world price and rand exchange rate. Deductions can also change due to location differentials and marketing cost changes. The farm gate price of R2810.00 will be used to determine the sensitivity analysis.

Table 2.3: Maize sensitivity analysis for the season 2021/22

MAIZE: SENSITIVITY ANALYSIS – TOTAL COSTS (Variable cost + Overhead cost) R/ton										
						Current				
SAFEX price(R/ton)		2150	2400	2650	2900	R 3 150	3400	3650	3900	4150
Producer price(R/ton)		1810	2060	2310	2560	R 2 810	3060	3310	3560	3810
Yield (t/ha)	5.5	-820	-570	-320	-70	180	430	680	930	1180
	6.0	-601	-351	-101	149	399	649	899	1149	1399
	6.5	-416	-166	84	334	584	834	1084	1334	1584
	7.0	-257	-7	243	493	743	993	1243	1493	1743
	7.5	-119	131	381	631	881	1131	1381	1631	1881

Source: Grain SA, 2022

In Table 2.3, it is apparent that a farmer has to harvest a yield of 5.5t/ha with a SAFEX price of R3150.00. If the farmer's average yield per ton decreases, he or she will farm at a non-profitable level.

As seen in Table 2.1, input insurance is R356.17 while harvest insurance is R510.42 for the 2021/2022 season. Harvest insurance is an expensive expenditure. With all the other input costs on the rise, it is very important to find ways that can mitigate risk in such a manner that it can compete with high insurance costs.

2.5 Insurance products available to manage yield risk

An insurance product's goal is to lower financial risk and make unintentional loss controllable. It is accomplished by exchanging a payment of a small amount known as an insurance premium – to a professional insurer – for the assumption of the risk of a substantial loss and an obligation to pay the large amount in the event of such a loss (III, 2022). In the event of a disaster, a certified loss assessor conducts an objective loss assessment to determine the compensation due to the buyer of the insurance product (Raithatha & Priebe, 2020).

Producers buy insurance to compensate for negative economic consequences of bad weather, for example, frost and hail or revenue loss because of agricultural commodity price declines. Agriculture insurance is said to have begun in South Africa in the early 1900s (Mahul & Stutley, 2008). The insurance industry is currently dominated by private investors who set premiums based on historical data. According to the Insurance Information Institute (2022), there are two major types of crop insurance: multiple peril crop insurance (MPCI) and crop-hail insurance.

MPCI insures crop losses, including lower yields, caused by natural events such as destructive weather (hail, frost, damaging wind), disease, drought, fire, flooding, and insect damage. MPCI is regulated and it is sold and serviced by crop insurance companies and agents in the private sector. MPCI is chosen by more than 90 per cent of farmers who purchase crop insurance in the United States (III, 2022). The cost of insurance, as well as the amount an insurer will pay for losses, are both determined by the value of the specific crop. However, the difficulty is distinguishing between crop losses caused by uncontrollable factors such as drought and crop losses caused by a lack of acceptable farming practices (Santam, 2016). As a result, to qualify for cover the producer must follow a set of norms and rules. This includes acceptable emerging dates for the crop and acceptable plant density (Santam, 2016). Farming practices that can be considered the proven norm for the area or the same production conditions must be followed in principle.

Although it is still possible to utilize a good crop for some years after the ideal planting window has passed, the risk is extremely high. Frost is one of the most significant threats associated with late planting. It should be noted that there is already a 10–30 per cent chance of frost in South Africa's cooler summer grain-producing areas by mid-April (Santam, 2016). Another factor is a lack of heat units, which is especially problematic in wetter years when temperatures are lower and there is more cloud cover.

It is critical to follow the guidelines to avoid the risk of a poor crop; otherwise, the multi-risk insurance coverage will not be activated. An effort should also be made to farm more sustainably, with less crop volatility between seasons, so that acceptable crops can still be produced in bad years.

Agriculture Crop insurance was founded and developed in South Africa in 1929, when a group of farmers in the Eastern Free State formed a pool scheme to insure them against extensive hail damage (Santam, 2022). Crop insurance accounts for a small portion of the market in South Africa. In terms of premiums, the agricultural insurance market for crop- and harvest-related insurance in primary agriculture is approximately R1.5 billion (Wiese, 2019). This amounts to roughly 30 per cent of the total value of all crops in South Africa. In the commercial sector, MPCI has a market penetration of only 17 per cent of the planted surface area and is negligible in the small-scale sector (SAIA, 2013). To determine crop insurance take-up, the areas covered by crop insurance are compared to the areas planted. For many years, this has remained relatively stable at around 40 per cent in South Africa (Kriel, 2021). MPCI market penetration in South Africa is very low because premiums are expensive due to high weather event volatility – specifically, a frequent incidence of drought – as well as high transaction costs of offering the insurance product to a wide distribution of clients in remote areas. The South African Insurance Association (SAIA) and the government developed a plan in 2021 for a 3.2 billion Rand 10-year state subsidy scheme aimed at resolving market issues (Rumney, 2021). The scheme will subsidize 25 per cent of commercial grain and oilseed farmers' MPCI premiums (Rumney, 2021).

Farmers can diversify their risks and manage their risk management costs in a variety of ways. One way to transfer risk is to use insurance as collateral for production credit when their insurance assets are protected in the event of a loss. Crop insurance is just one of many tools available to help reduce production risks. Other methods include setting up a contingency fund, using hail nets, and diversifying production over various geographical areas.

Farmers should be aware of their climate-related risks as well as their uncertainty capacity. Depending on this, they should develop a risk management plan that is reviewed on an annual basis to account for changes in the risk profile or uncertainty capacity.

Farmers must weigh the financial implications of each of these options against their risk appetite. Many farmers, for example, cannot afford to self-insure by establishing a contingency fund to cover their entire harvest, so they may end up with a fund that covers a portion of the harvest while purchasing insurance coverage for the remainder of the land (or planting a lower-risk crop on it).

In many developed countries, insurance is heavily subsidized. The US government subsidizes up to 60 per cent of the premium, resulting in the majority of farmers in that country purchasing multi-peril coverage (Kriel, 2021). This is not the case in South Africa.

The transition from all-risk/multiple-peril crop insurance to rainfall-based insurance necessitates the separation of risk into specific event risks. Rainfall-based insurance is a weather index insurance that provides farmers with an affordable and accessible way to manage agricultural risks that pay out benefits for losses caused by weather and catastrophic events based on a predetermined index, such as rainfall level (Raithatha & Priebe, 2020). Millions of farmers in Kenya and India use weather index coverage, but it has never been traded on a futures exchange in South Africa (Rumney, 2021). It automatically pays out when a metric, such as rainfall, is above or below a certain level, eliminating the need for costly site visits to assess claims. Specific event risks are concerned with the economics of certainty, and our expected utility, mean-variance-based insurance framework is no longer effective as an economic model (Turvey, 1999). Fortunately, the economics of rainfall insurance is based on much fewer strict requirements than conventional models and can be easily justified through an argument of common sense and sensibility rather than risk aversion and expected utility.

Given the uncertainty of agriculture and the cost price squeeze experiences, farmers must find alternative ways in managing yield and price risk.

2.6 Weather derivatives

Commodity crop insurance is like other types of insurance. It is complex with difficulties and associated with ambiguities; it is, therefore, appropriate to investigate alternative agricultural insurance structures.

2.6.1 Development of weather derivatives

As an alternative, a market for tradeable risk was created. Weather derivatives were developed in the United States in 1999 as a means of mitigating financial losses from climate risks (Turvey, 1999). The increased focus on climate-related risks has become a major driver of demand for financial products that offer protection against adverse weather and climate change outcomes. Weather derivatives are a fast-growing derivatives sector. The Chicago Mercantile Exchange (CME) Group list the first standardized weather futures contracts based on weather indexes from ten US cities, in 1999, with Amsterdam, London, and Tokyo, Japan, being added for global coverage (Sutton-Vermeulen, 2021). The CME now offers these products in over 30 cities across three continents (CDI, 2021). This recent increase in climate-related risk awareness has resulted in increased activity in CME Group weather futures and options trading volumes, as well as the addition of new market participants, such as hedge funds and asset managers (Sutton-Vermeulen, 2021). Futures volumes in 2020 have increased by 60% year to date, with a net value of $750 million, while options volumes have increased by 143% year to date, with a net value of $480 million (Sutton-Vermeulen, 2021). Weather derivatives are typically traded on an index that measures a specific aspect of weather like precipitation, wind or temperature.

2.6.2 What are weather derivatives

Weather derivatives are similar to put options, call options, and swaps in the way that they can be traded as derivative products or sold directly as insurance products (Turvey, 1999). Weather derivatives operate in the same way as insurance. The seller of a weather derivative (the insurer) agrees to pay a certain amount to the buyer (the insured) in exchange for a premium if a weather-related event occurs or the buyer suffers a weather-related financial loss before the contract expires. If no damages occur before the contract expires, the seller's profit is the premium or the price of the derivative at its inception (CDI, 2021). A weather derivative contract has the following characteristics: (1) a start and end date for the contract period, (2) a measurement station, (3) a weather variable measured at the weather stations over the contract period, (4) a weather index that gathers the weather variable over the contract period, (5) a pay-off function, according to which the derivative contract is settled shortly after the contract period ends; and (6) for some types of weather derivative contracts, a premium paid from the buyer to the seller at the start of the contract (Jewson and Brix, 2005).

The payout of weather derivatives is based on weather indices. The weather index is the underlying asset of weather derivatives, and because the weather is not a physical good, there is no spot market for weather indices. At maturity, weather derivatives are financially settled based on the difference between the underlying weather index from the predetermined strike index. The strike level is commonly calculated as a 10-year historical average and reflects the expected value of the weather index (Pres, 2009). Considering the noticeable climate change, recent weather may be a more accurate representation of projected future weather, implying that a shorter weather observation would provide a more reliable strike level. It is not essential to keep the contract until maturity because investors can offset their positions in the market before maturity (Tauser and Cajka, 2014).

2.6.3 The difference between weather derivatives and insurance products

Weather derivatives and insurance products have similarities, but they differ in a lot of ways. Weather derivatives cover low-risk, high-probability occurrences; whereas weather insurance in general, covers high-risk, low-probability occurrences, as defined in a fully personalized policy (Buckley *et al.,* 2002). Hurricanes, earthquakes, and tornadoes are examples of low-probability, catastrophic weather events covered by insurance. Derivatives, on the other hand, cover higher-probability events such as a drier-than-expected summer or a rainier summer (Buckley *et al.,* 2002). Currently, insurance programs are more often used in the world as a risk management tool than weather derivatives. However, they are regarded as effective instruments for hedging against the risk associated with weather variability in today's climate and may become even more appealing in future climates characterized by increased variability and frequency of extreme weather. The payoff structure of an exchange-traded weather derivative is the same as that of an insurance product. In financial markets, the two are distinct because the regulatory regime for selling insurance products differs significantly compared to over-the-counter (OTC) derivatives. In addition, there are significant differences in the principles used for insurance products versus financial derivatives. Weather derivatives are based on a specific "weather" trigger (e.g., heating degree days) rather than proof of loss (e.g., temperature exceeding a specified threshold and period) and are thus easier and less expensive to administer than other alternatives like insurance (Buckley *et al.,* 2002). The settlement process for insurance derivatives is typically faster and less onerous than for traditional insurance. Derivatives pay out instantly, triggered by the movement of an index that does not need to be interpreted. An event either occurs or does not occur. Insurance claims can take a long time and cost a lot of money to process (CDI, 2021).

Weather derivatives offer the advantage that the transaction costs are low, and payoffs are determined in a transparent way (Odening *et al*., 2007). They are not affected by adverse selection and moral hazards, making them a better option as insurance products. Additionally, a large amount of risk remains with the producer when using weather derivatives because individual yield variations are not generally correlated with the relevant weather variable (Odening *et al*., 2007). The risk also increases due to the geographical basis risk.

2.6.4 Basis risk

Basis risks arise when the derivatives price and the underlying instrument do not move in the same direction (Geyser & Van der Venter, 2001). This happens when different weather conditions happen at different weather stations, like rainfall that is measured differently on the farm than at the weather station. Index insurance may not always result in proper compensation for yield losses; therefore, it could fail to pay farmers the adequate amount and they could suffer income losses (Dalhaus *et al*, 2018). Access to data, both in terms of regulatory requirements and purchase cost, may pose problems. As a result, the greater the ease of access and the lower the cost of weather data, the greater the opportunities for developing weather derivatives. The main reason for using weather derivatives in agricultural production is the presence of a clear and satisfying relationship between the production variable and the weather factor (Stoppa & Hess, 2003). Weather derivatives for agriculture, like any other weather derivative, must be measurable; historical records must be adequate and available; and all parties involved in the transaction must regard such measures as objective and reliable.

To ensure the effectiveness of hedging weather derivatives, the interdependent problems must be solved like the statistical modelling of relevant weather variables, the quantifying of relationships between weather variables and production, and the development of a theoretical consistent pricing model (Odening *et al*., 2007)

2.6.5 Weather derivatives in agriculture

Weather derivatives can benefit a broad range of sectors such as construction, energy, insurance, banking, agriculture, leisure and entertainment as all these sectors can be adverse affected by weather. The goal of weather derivatives is to allow businesses to protect themselves against adverse weather. Construction contracts, as an example, are frequently designed with incentive clauses, which are frequently based on the completion date. If the construction company finishes ahead of schedule, they are paid a set amount per day. If the project is completed after the deadline, the construction company must pay a daily penalty. Weather is one of the most common causes of missed deadlines, making weather derivatives extremely important for construction companies (Alzarrad *et al.*, 2017).

Agriculture has traditionally been regarded as a highly weather-sensitive economic sector. The goal of weather derivative implementation, like any other risk management tool, is to reduce the volatility of revenues and/or costs caused by non-catastrophic weather volatility. The purpose of weather derivative payouts is to compensate for lost revenues and extra costs caused by bad weather.

Weather derivatives have been studied and proven to be effective in grape, maize, wheat, barley, soybean, and cotton production (Ivana *et al,* 2016). Zara (2010) investigated the efficacy of weather derivatives in the production of wine grapes in France. The results show that the use of a strangle option strategy reduces the volatility of the economic value of grape production by 22.06 per cent when compared to the economic value of grape production without the use of weather derivatives. Vedenov and Barnett (2004) investigated the effectiveness of weather derivatives in corn, soybean, and cotton production in the United States. The results show that the weather derivatives application reduces output semi-variance by 16.6 to 77.1 per cent. Call options were based on the temperature index, while put options were based on a rainfall index. The results show that using weather derivatives reduces semi-variance regardless of the underlying index. However, in terms of mitigating weather risk in corn production, temperature options outperform rain options.

Spaulding *et al*. (2003) examined the effect of rain put options on maize and wheat production in Romania. According to the findings, the weather derivatives application can reduce output variation by 39%. Torriani *et al*. (2008) investigated the efficacy of rain put options in Swiss maize production. The authors use value-at-risk (VaR) as a risk measure, and the results show that using weather derivatives reduces the maximum possible loss due to adverse weather. Based on the literature reviewed, it can be concluded that weather derivatives' results vary according to crop, geographical location and period.

Locally Wang *et al*. (2013) studied farmers' demand for weather index-based crop insurance and concluded that insured growers can benefit more from multivariate weather indices. Geyser and Van der Venter (2001) studied the feasibility of weather derivatives in the South African agricultural market. They conclude that weather derivatives will be beneficial for farmers and will only be successful if their introduction goes along with the educational process. Geyser (2004) examined the application of weather derivatives in South Africa by the benefits of rainfall options as a yield risk management tool and suggested an options strategy for agriculture. The study concluded that the availability of adequate weather statistics does not appear to be a barrier to the development of weather derivatives in agriculture. Access to the data, both in terms of bureaucratic procedures and purchase cost presents challenges.

2.6.6 Rainfall options

Rainfall options can be built in a variety of ways. According to Geyser and Van der Venter (2001), farmers can "lock" in a certain amount of rainfall during a specific time through options in three different ways.

The first option could be to buy a long call or put option, or a combination. The farmer would use a long call option if he or she wants to hedge against abnormally high rainfall. For example, the farmer could buy a call option for three months, which could be the possible threat of too much rain and floods. If the average rain in the area is for example 300mm over a certain period, the farmer would hedge against surplus rainfall. The farmer can also buy a put option for the period when it's crucial for the maize plant to receive rain. If it is important for the maize to receive rain between January and February, for example, the farmer can buy a two-month put option. When the farmer receives less than a certain amount of rain during that period, the option will exercise. If the farmer needs a certain amount of rainfall during a specific period, for example, from January till March, the farmer can buy a straddle option, a combination of a put and a call option. The farmer is then protected against too much or too little rainfall during that period.

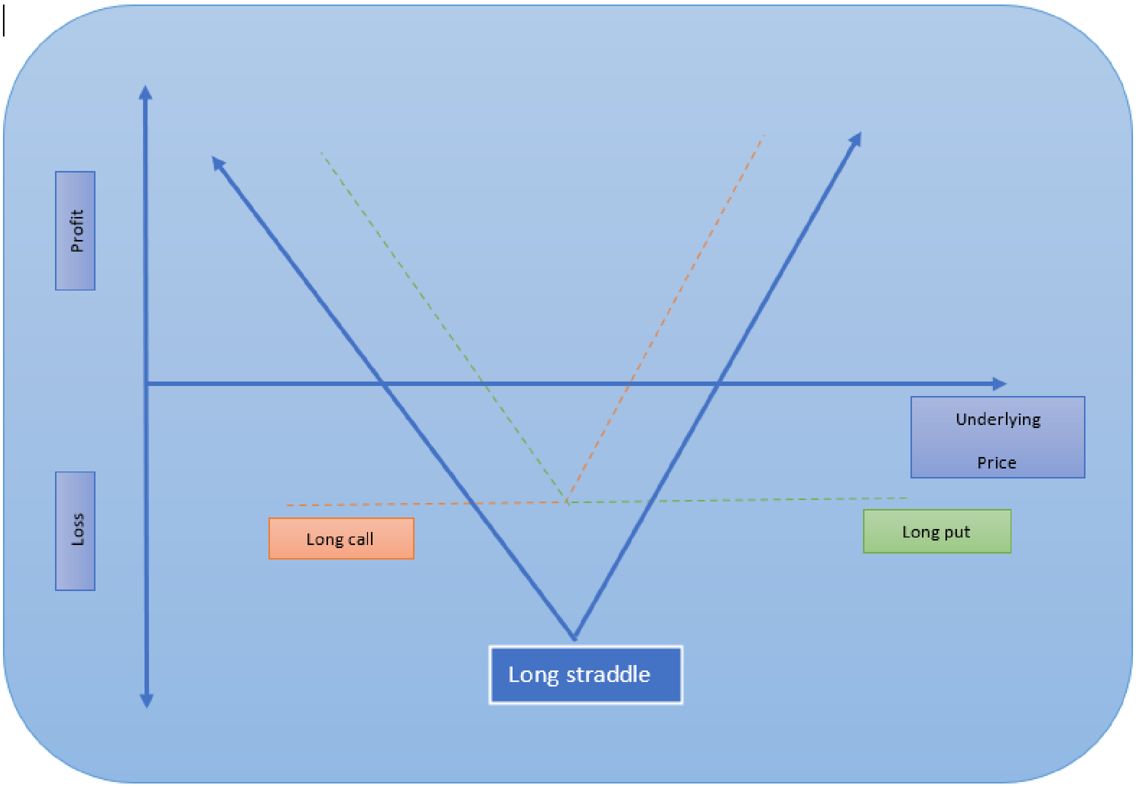

Figure 2.4: The net effect of a long call and a long-put option with the same strike price and expiration date
Source: Bang, 2019.

The rainfall option would have a strike rate based on the historical rainfall data for the specific area with a rainfall index. A certain amount of rain in millimetres for a specific period would determine the strike point. For example, if the average rainfall for the specific area between January and March is 150mm, a three-month call option for that period will have a strike rate of 150mm. The rain that falls during that time will be the actual quantity and will determine the payout of the option. The Rand value that is pre-set per millimetres, that is more or less than the strike, would determine the pay-out option.

The application of weather derivatives is intended to smooth revenues, cover excess costs, reimburse lost opportunity costs, stimulate sales, and diversify investment portfolios (Leggio, 2007). Weather derivatives can help farmers offset complex weather exposure.

2.7 Conclusion

Agriculture is critical to promoting economic growth, alleviating poverty, and improving food security in Southern Africa. The agricultural sector employs over 800,000 people in South Africa (Rumney, 2021). South Africa's well-developed commercial farming sector is the backbone of the country's agricultural economy, with the best growth rate of any economic sector in 2020, at 13.1 per cent contributing to the GDP (ITA, 2021). As mentioned before, maize is a staple food in South Africa and the maize sector had the largest contribution of 2.8 per cent in the agriculture sector to GDP growth in 2020 (BFAP, 2021).

Farmers are constantly dealing with and managing various types of agricultural risks (Huirne, 2003). Risk inherently involves negative outcomes, such as lower yields and incomes, as well as catastrophic events, such as adverse weather and food insecurity, although higher expected returns are typically one of the positive rewards for taking a risk. Therefore, farmers must deal with and manage multiple risks at the same time, which can have compounding effects (van Winsen *et al*., 2013).

The emphasis on climate-related risks has been a major driver of demand for financial products that provide protection against adverse weather and climate change outcomes. As previously mentioned, weather derivatives were created in the United States in 1999 to help mitigate financial losses from climate risks. (1999, Turvey). The CME now sells these items in over 30 cities on three continents (CDI, 2021). In South Africa, weather derivatives are not commonly used, and hedging opportunities are limited. In South Africa, crop insurance grew from a few farmers in Ficksburg who started with a pool scheme to protect themselves against hail damage, to successful weather-based insurance sold by different private companies.

The increased input costs and unpredictability of weather, increases the uncertainty of farming profitability. Therefore, farmers experience a lot of pressure because of the cost-price squeeze. To help manage the risk of adverse weather and low yields, there is currently crop insurance available in South Africa. The disadvantage of weather-based crop insurance is the expensive premium costs. It is, therefore, necessary to investigate weather derivatives as an alternative risk management tool. Both crop insurance and weather derivatives can be used as a hedging mechanism against yield risk to protect farmers.

The main objective of weather derivative applications, like any other risk management tool, is to reduce the volatility of revenues and expenditures caused by non-catastrophic weather volatility. The goal of compensation paid by weather derivatives is to cover lost income and extra costs caused by bad weather. As a result, weather derivatives can be considered effective if their use reduces the volatility of realized profits, thereby lowering the uncertainty, in other words, the riskiness, of future income. Profit volatility is reduced, which improves the company's credit rating and ensures lower borrowing rates.

If it is found that rainfall options are financially feasible for farmers in South Africa, it will not only manage price risk but yield risk as well, which could benefit farmers in enabling them to keep on farming in a forever-changing environment. The uncertainty of weather exposure requires a complex weather derivative design. Weather derivatives are considered effective if their use reduces the volatility of the yield's economic value.

The next chapter will look at the theoretical and empirical aspects of the research. The chapter will focus on the different variables that will impact the relationship between rainfall and yield, the research approach, the data collection, how the data will be processed, and the different statistical methods used.

Chapter 3

Data and methods

3.1 Introduction

The research aims to determine whether weather derivatives can be used by maize farmers in the North-West Free State as a tool to manage yield risk caused by adverse weather. This chapter's purpose is to present both theoretical and empirical aspects of the research method used in this study.

The empirical portion of this study will be conducted using a quantitative research method. This study will use time-series data to determine the ideal amount of rainfall during the growing period of maize for profitable yields. The focus area will be the North-Western Free State region where the growing period of maize runs from the end of October up to March, with planting normally commencing in the second half of November. The period 2000/01 to 2020/21 marketing season was chosen based on the following:

- Derivative trading in maize started in 1996 in South Africa and was well adapted by the beginning of the twenty-first century.
- The North-Western Free State is chosen as the study area because the Free State produces the most maize in the country and the North-Western Free State is known for its water table soil, which is sensitive to rainfall variability.
- Cultivar development and new farming practices had a huge impact on yield and these adaptions have been captured since the 2000/01 marketing season.

Secondary data were obtained from the South African Weather Service, SAGIS, Grain SA, Senwes, and the Johannesburg Stock Exchange. The data will be transferred to Excel before being imported into EViews 12. Relevant descriptive statistics will be drawn, correlations calculated, and multivariate regressions estimated to determine potential statistically significant relationships. In order to reach the objectives of the study, the most important empirical modelling will be to determine the relationship between yield and rainfall in order to determine and price rainfall options. Scenario analysis will also be done to see if a farmer would have been in a better financial position if he or she made use of a rainfall derivative as a hedging tool against yield risk.

The chapter describes each variable in Section 3.2. In Section 3.3, the methodology is discussed followed by Section 3.4, where the research approach and data collection will be discussed; Section 3.5 concludes with a chapter summary.

3.2 Variables

This analysis will be divided into two different subsections to help define if weather derivatives can be used as a yield risk management tool. The first step is to determine specific rainfall levels (too little and/or too much) that negatively impact maize yield in the North-Western Free State. To do so, the relationship between rainfall and yield will be established. The second important section is to determine the price of the rainfall derivative. This is necessary to determine whether rainfall derivatives are financially feasible and profitable for a farmer compared to regular MPCI. The variables that will impact the pricing of rainfall derivatives, both dependent and independent, are subsequently explained in this section.

Figure 3.1 presents the steps in the methodology that will be used in the evaluation of rainfall options.

1. Analyze the monthly rainfall data of all rainfall stations in the North-Western Free State.
2. Determine rainfall variations during specific times of each season.
3. Determine average yield per hectare per season.
4. Determine the relationship between yield and different months of rainfall for each season.
5. Determine extreme rainfall levels that impact yields.
6. Determine crop profitability levels (break-even-point).
7. Do a sensitivity analysis to determine necessary profitable yields.
8. Use YaR to determine the percentage of harvest that needs to be hedged.
9. Price rainfall option.
10. Compare rainfall options to agriculturial insurance.

Figure 3.1: General framework for calculating rainfall options
Source: Compiled by author

The steps for evaluating a rainfall option are detailed in the following sections.

3.2.1 Rainfall and yields

Rainfall is the most important factor influencing maize production in South Africa (Le Roux, 2009). Climate variability accounts for up to 80% of the year-to-year variability in crop yields in many countries (Sivakumar, 2006). Weather fluctuations have an impact on farmer welfare because crop yields vary from year to year. It is, therefore, important to examine the relationship between rainfall and maize yields.

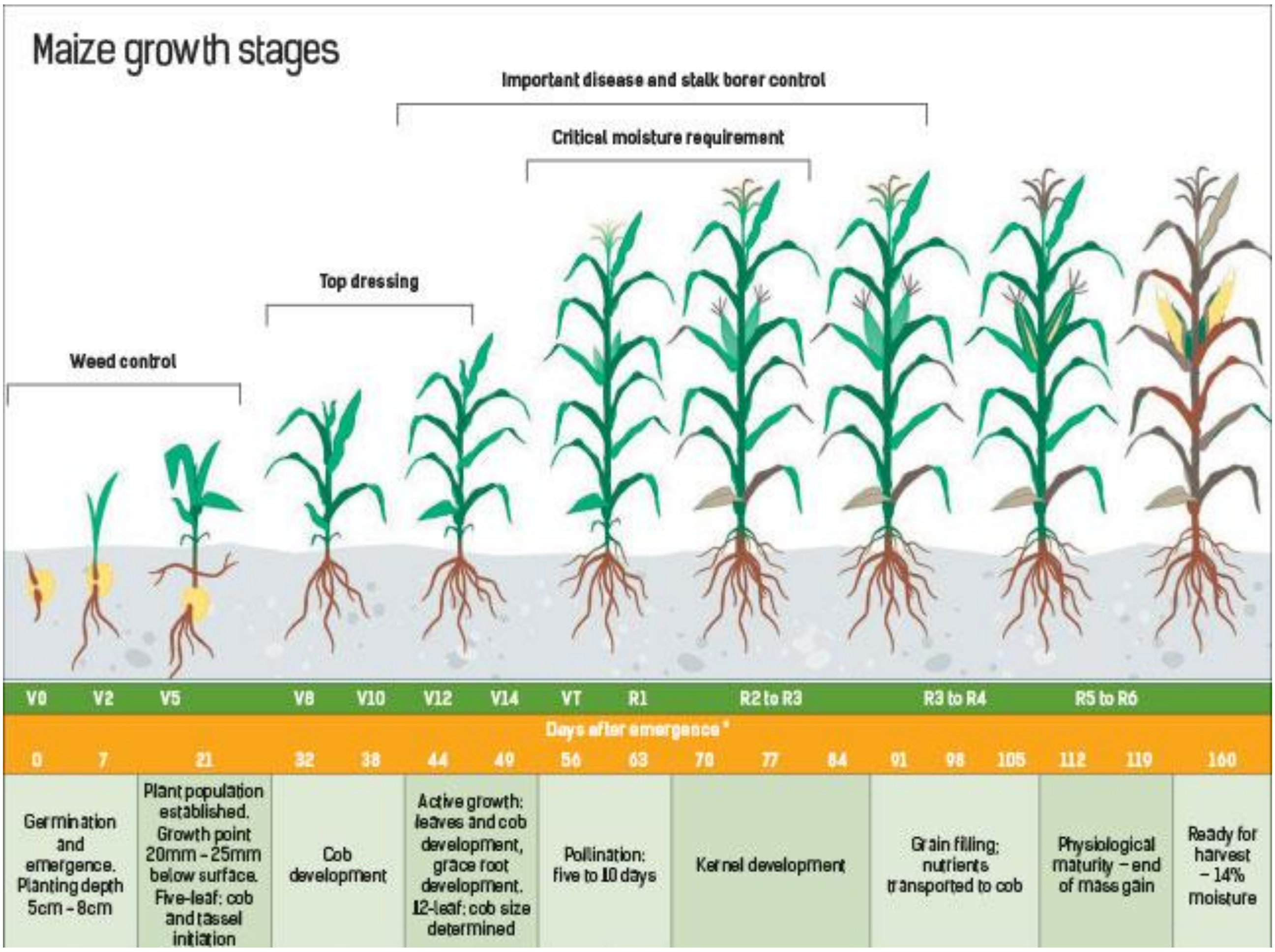

Figure 3.2: Growth cycles of maize and water required at each stage
Source: Pringle, 2017.

As portrayed in Figure 3.2, a maize plant needs the most rain between days 50 to 85 days after planting. This is during the transition period from vegetative growth stage to the reproductive growth stage. During the last few days of vegetative growth, stress will delay cob development more than tassel development, resulting in pollen production before silks emerge. Severe stress can be extremely harmful. If the leaves are already wilted in the morning due to moisture stress, crop loss of up to 4% per day is possible (Pringle, 2017). Prolific hybrids are typically more stress-tolerant than single-cobbing hybrids because cob development is less restricted under the same conditions. At this stage, hail can cause up to 100% yield loss. During the reproductive development, the reproductive stage begins when the silk appears. Pollination takes between five and ten days. You should ensure that the maximum number of potential kernels develop into kernels as the ovules are fertilized. At this time of year, maize is sensitive to stress. Stress can cause kernel abortion at the cob tip, and wilted leaves from morning moisture stress can result in a 7% yield loss (Pringle, 2017). Hail can result in a 100% yield loss due to defoliation. Leaf diseases are another potential issue.

In South Africa, the critical window is usually from January to March, during which stage the kernel is formed (Geyser, 2004). The relationship between rainfall and maize yield must be determined before weather derivatives may be evaluated in South Africa. It's worth noting that maize yield is affected not only by rainfall but also by the overall climate (Geyser, 2004). Maize is also sensitive to temperatures that are too high, especially during the pollination stage. High temperatures cause the pollen to die before any pollination can take place. This study assumes that temperature is indirectly reflected in rainfall data since periods of low rainfall are normally associated with periods of higher temperature.

Rainfall is often expressed in millimetres per day (mm/day), which represents the total depth of rainwater (mm). In terms of volume, with a rainfall of 1 mm, every square metre receives 1 litre of rainwater. Rainfall of 1 mm supplies 0.001 m^3 or 1 litre of water to each square metre of the field. Thus, 1 ha receives 10 000 litres per 1 mm of rain. During the peak growing season, a vigorously growing maize plant requires approximately 2-3 litres of water per day, with an average water consumption ranging from 2.5 to 4.3 mm/day (Ikisan, 2022). Therefore, the daily water requirement of a maize field with a plant population of 35 000 plants is 8.75 to 15.05 mm per day on average.

Excessive water or flood conditions are not tolerated by the crop. Crops grown in waterlogged conditions become pale, grow poorly, and lose their uniformity. Waterlogging in a maize field for only one day, damages the crop stand for three days, nearly ruining the entire crop (Ikisan, 2022). As a result, efficient drainage is often more important than irrigation. This fact also shows that maize plants are susceptible to too much rainfall.

3.2.1.1 Average monthly rainfall

In the next step, the average rainfall of each month from the year 2000 to 2020 will be compared to the average yield of maize during the specific year to see the relationship between maize yield and rainfall.

The average of all the weather stations will be combined to get the average rainfall for the North-Western Free State region.

3.2.1.2 Rainfall variations during different periods

In this step, the focus will move to rainfall frequency and rainfall variation during specific times of a season. The averages of November up to the end of December will be combined as this is typically the planting window in this area. The next period under consideration will be from January to March as this is a very important window in the season. During this period, favourable weather conditions are important because these are the critical forming kernel stages (see Figure 3.1). The last period of combined rainfall averages will be from April to June, which is after the kernels are formed and the plant begins to dry off.

Together with the calculated rainfall for each period in the growing season, the overall average annual rainfall per season will also be compared to the recorded yields.

3.2.1.3 Average seasonal yield

Historical data of the average yield of maize per season will be compared to rainfall averages during the identified periods per season. This will help to find correlations between maize yield and rainfall.

3.2.1.4 Relationship between yield and different rainfall periods

According to Geyser (2004), a correlation coefficient can be used to determine the degree to which maize yields and rainfall are linked. When the correlation coefficient is -1, it suggests that even if the rainfall is lower than projected, the yield will always be higher. A correlation coefficient of 0, on the other hand, indicates that maize production and rainfall have no relationship. Movements in the same direction are represented by a very positive, statistically significant correlation value up to a maximum of 1. This means that the more rain there is, the higher the yield, and vice versa. Correlation calculations will be supplemented with regression analysis, where yields are regressed on rainfall volumes during the identified critical periods. These regressions will enable the study to forecast expected yields at various levels of rainfall in the study area.

3.2.1.5 Determine rainfall levels that impact yield

The more important periods during the life of a maize plant are already described in Section 3.2.1.2 and these different periods will be used in this section to determine the sensitivity of maize yield concerning rainfall. The focus will then move to the rainfall levels that trigger below-average yields. This can either be too much or too little rainfall. By determining the outliers, it will be possible to know the strike level of rainfall that a farmer needs to hedge against.

3.2.2 Crop profitability

As previously mentioned, a sensitivity analysis will determine the profitable level of yield necessary to break even financially. To be able to do a sensitivity analysis, historical records of maize crop budgets will be analysed. The crop's profitability will be calculated by deducting the expenses from the income.

The cost to plant the crop will determine the yield needed to be harvested combined with the spot price of maize to determine when the crop will be profitable. More detail will be provided in the next section of the sensitivity analysis.

3.2.2.1 Sensitivity analysis

To determine the Value-at-Risk (VaR) and the percentage of the crop that needs to be hedged, the yield level that is necessary to break even is required.

The sensitivity analysis will combine all the input costs for the specific season, the average July spot price (normal harvest time for the North-Western Free State) and the different levels of yield. An analyst can utilize this knowledge to comprehend how a change in one variable impacts the other variables or outcomes by using sensitivity analysis to forecast the consequences of an event given a specified range of variables. It is a method used for investigating how various independent variable values, given a certain set of assumptions, can affect a particular dependent variable.

To determine this point of yield, a sensitivity analysis will be done over each season.

3.2.2.2 Value-at-Risk

VaR is a financial measure that estimates the risk associated with an investment (CFI, 2022). VaR is a statistical technique used to calculate the amount of potential loss that could occur in an investment portfolio over a given period due to adverse movements in the underlying market factors. The probability of losing more than a certain amount in a given portfolio is expressed as VaR (CFI, 2022).

Though VaR was created with the needs of financial institutions in mind, it can also be used for other purposes, like the agriculture sector (Gloy & Baker, 2001). In addition, Manfredo and Leuthold (2001) use VaR methods to estimate the market risk of cattle feeders. Weather is the primary cause of yield variation, but there are other causes as well, including crop diseases, the adoption of new technology, and the extension of crop production into the more marginal soil (Geman, 2015). Since crop production is globally diversified, the global average yield is somewhat protected against changes in specific countries. We use the financial concept of “Value-at-Risk” to calculate “Yield-at-Risk (YaR)”, which quantifies the likelihood that yield will negatively deviate from the trend.

VaR will be used to find outliers between yield and profits. Combined with a sensitivity analysis, the YaR will explain how sensitive a farmer is to changes in yield. The expected profit can be determined with historical input costs, average prices and average yields. Changes in yields, higher or lower, affects grain producers’ financial position. Lower yields impact a farmer negatively to the degree that he or she will no longer make a profit. YaR will determine the level of risk a farmer has, compared to yield changes.

This model will help determine how sensitive the farmer is regarding yield, for his farm to still be financially feasible. This model will provide the percentage he or she needs to hedge. The goal of determining the VaR in terms of yield is to find the correlations with rainfall.

The Value-at-Risk will be calculated as follows:

$$VaR = \mu + \sigma N^{-1}(X) \tag{3.1}$$

Where:

- μ is the mean loss of the portfolio value
- σ is the standard deviation of the portfolio
- $N^{-1}(.)$ is the inverse cumulative normal distribution[3]
- X is the confidence level

The change in portfolio value over time is regularly distributed, according to a basic assumption. For short time horizons, μ is frequently believed to be zero. VaR is then proportional to σ for a given confidence level[4]. The confidence level will be determined by the sensitivity of profit towards yield deviations.

[3]Cumulative normal distribution can be calculated using NORMSINV in Excel

[4] In VaR analysis, the 95 per cent and 99 per cent confidence levels are the most frequently applied confidence levels (Manfredo & Leuthold, 1999).

3.2.2.3 Price rainfall option

The option price for rainfall derivatives will be divided into two options, namely a call option and a put option.

$$P_{call} = k \times \max(S - I_t, 0) \tag{3.2}$$

Where

- k is the pre-agreed constant factor that determines the payment unit of the weather index
- S is the strike rate
- I_t is the weather index

A call option is a contract where the buyer and the seller pre-agree on a contract period and the weather index (I_t) for the basis of the contract. The seller will receive a premium from the buyer at the beginning of the contract. If I_t is greater than the pre-agreed strike (S) during or at the end of the contract, the option will realise, and the seller pays the buyer.

$$P_{put} = k \times \max(S - I_t, 0) \tag{3.3}$$

A put option is similar to a call option contract in that the seller pays the buyer when I_t is less than S.

With a call and a put contract, the buyer must pay a premium to receive compensation when pre-agreed conditions are met (Geyser, 2004). The price of the option is calculated from the payoff expected to receive.

$$c = \exp\big(-r\,(T - t)\big)\,P \tag{3.4}$$

Where

- c is the premium buyers need to pay
- r is the risk-free market interest rate
- T is the maturity or expiration date of the contract
- t is the date when the contract is issued
- P is the payoff based on the predicted rainfall

3.2.2.4 Compare rainfall options to normal MPCI's

In this section, a comparison between rainfall options and MPC insurance will be drawn. With all the information at hand, an informed decision can be made to see if rainfall options are financially feasible. This section will focus on the financial comparisons between MPCI's and the costs of rainfall options.

3.3 Methodology

When it comes to predicting future changes, complexity and unpredictability are major concerns. Furthermore, while the future cannot be foretold, it is obvious that certain decisions or actions can have a positive impact on the future. Planners are being pushed in this regard to focus on the development of new methodologies and tools capable of dealing with complexity and ambiguity to successfully support policymakers in making more informed decisions to attain desired future outcomes.

The purpose of this study is to see if rainfall derivatives are financially feasible as a yield risk management tool. To complete the study, different scenarios will be analysed to see if a farmer would have been in a better financial position if they made use of rainfall derivatives.

The purpose of scenario analysis is not to forecast how the future will play out, but to consider several situations and how the economic environment might change in these scenarios. Participants then utilize these scenarios to examine what methods their businesses may employ if similar problems arise in the future. The goal is for participants to develop an understanding of how they might adjust their methods if the economic situation changes, as well as what strategies they would like to use regardless of the economic circumstances.

Scenarios are frequently viewed as effective instruments for acquiring information about future events (Giaoutzi *et al*., 2012). Scenarios are effective instruments for contemporary policy analysis in both the business and public sectors. Scenarios, in contrast to other deterministic, stochastic, or framework planning techniques for short to medium-term policy issues, are operational tools for complex decision-making marked by long-term and largely unpredictable uncertainty, where visioning of future developments is desirable for guiding the policy goals. They can also be used as 'educational' tools, to design a rational and transparent system for dealing with unknown futures rather than identifying the best possible future.

Scenario analysis will help to determine what elements commercial farmers and agribusinesses are considering while evaluating situations and how management techniques might change as a result of them. The relationship between yield and rainfall will determine a "baseline" scenario, which will help to provide information to see if rainfall options can benefit farmers as a yield risk management tool. A 'baseline' normative situation is sometimes contrasted with a 'scenario' that shows the shift in scenario analysis. The difference between the scenario and the baseline is used to calculate the economic and environmental impact of specific changes (Banse *et al.,* 2008).

Making the scenario analysis part of the study will help to utilize and investigate a wide range of future scenarios. This tool will navigate the unknown future by examining the probable business consequences of future occurrences and contemplating alternative scenarios. This technique will help to answer the question of whether farmers can benefit from rainfall options financially.

3.4 The research approach and data

Quantitative research is well-structured and can be considered reliable due to the preventive measures implemented to protect the data's reliability (Kumar, 2014). This is a legitimate approach because it makes use of secondary data, which is information gathered by institutions or individuals and not by the researcher personally (Welman & Kruger, 1999).

The research adheres to the positivistic paradigm, which means that the topic is well-established (Welman & Kruger, 1999). Since this is a well-established topic, researchers should use quantitative data and hypothesis testing to work with the data in an unbiased manner.

The secondary data were collected for twenty years, from 2000 to 2020. Earlier data were disregarded. During the 2000/01 marketing season, the first crop of genetically modified maize, where the Bacillus thuringiensis (Bt) gene was inserted into the maize hybrid to make them resistant to the maize stem borer, was harvested (Gouse *et al.,* 2016). This technology had a dramatic impact on maize yields. The period before the introduction of genetically modified crops is excluded from the study as yields increased substantially since the introduction of the Bt-gene and other genetically modified characteristics. Monthly averages of yield were determined. This period will explain if the different variables affect each other and if the average rainfall has an impact on the average yield of maize. The average July spot price of maize each year will be used as a basis compared to the input costs of each year. The July spot price is used as this is normally the time when the North-Western Free State farmers harvest their crops.

As mentioned, historical rainfall records will be obtained from the South African Weather Service and Senwes, historical yields will be obtained from the South African Grain Information Services (SAGIS), spot prices of maize will be obtained from the JSE, and historical input costs will be obtained from Grain SA.

After the relationship between rainfall and yield is confirmed, scenario analysis will be done, as mentioned before, to determine if rainfall options are an affordable alternative to mitigate risk in agriculture.

3.5 Conclusion

The main aim of this study is to resolve if weather derivatives are financially feasible for maize farmers in South Africa. The methodology in this chapter will help to determine if a rainfall option is financially feasible for maize farmers as a risk management tool. When there is a clear relationship between the variables it can help market participants to make better-informed decisions.

This chapter described the different variables that will impact the different scenarios like rainfall and yield. The chapter also looked at the research approach, the data collection, how the data will be processed, and the different statistical methods used.

Chapter 4

Empirical Results

4.1 Introduction

In this chapter, the focus will be on the relationship between rainfall and yield. This will be done through different statistical tests. The data will further be analysed to determine if rainfall variability during the different growing stages of the plant has an impact on the yield of maize. After the relationship between yield and rainfall is confirmed, outliers of the amount of rainfall that negatively impacts yields will be explained. The focus will thereafter move to the feasibility of rainfall options.

To determine if rainfall options are financially feasible for the farmers, a price-yield sensitivity analysis will be conducted to determine the break-even price and yield for maize in the North-Western Free State.

The Yield-at-Risk (YaR) model will help determine the correlation between yield and profits and how sensitive a farmer's profit levels are to changes in yield. By determining the VaR, the correlation between yield and rainfall can be made. Finally, rainfall options would be priced and compared to normal MPCIs.

4.2 The data

The data for this study covers a period of twenty years and runs from the maize planting season of 2000/01 up to 2020/21. To analyse the relationship between rainfall and yield, the average monthly rainfall each season will be compared to the average yield of maize harvested during that specific season. This will help determine the relationship between rainfall and yield, and also at which time of the growing season the plant is most sensitive to rainfall variability impacting yield.

The monthly rainfall data was obtained from the South African Weather Services and Senwes; it was then extracted and imported into Excel. The average yield of maize for each season was obtained from data was achieved from the Crop Estimates Committee (CEC) of the Department of Agriculture Land Reform and Rural Development (DALRRD), and then imported to Excel. the average rainfall during the critical kernel forming stage, which runs from January to March, and the average rainfall during planting time, which runs from November to December in the area of focus, the North-Western Free State, was calculated in Excel.

All the data were processed in Excel and imported to Eviews to conduct different statistical tests. The different tests aim to find the relationship between rainfall and the yield of maize, and to see if there are any correlations between yield and the specific months when the rain was recorded.

4.2.1 Average rainfall data for each month

As the focus area for the study is the North-Western Free State, the following weather stations were included as this area is known for its water table soil. These weather stations include:

- Bultfontein
- Wesselsbron
- Hoopstad

For the years 2000/01 to 2020/01, Figure 4.1 shows the annual rainfall and yield averages of the three weather stations. The variability of the recorded annual rainfall is evident in Figure 4.1.

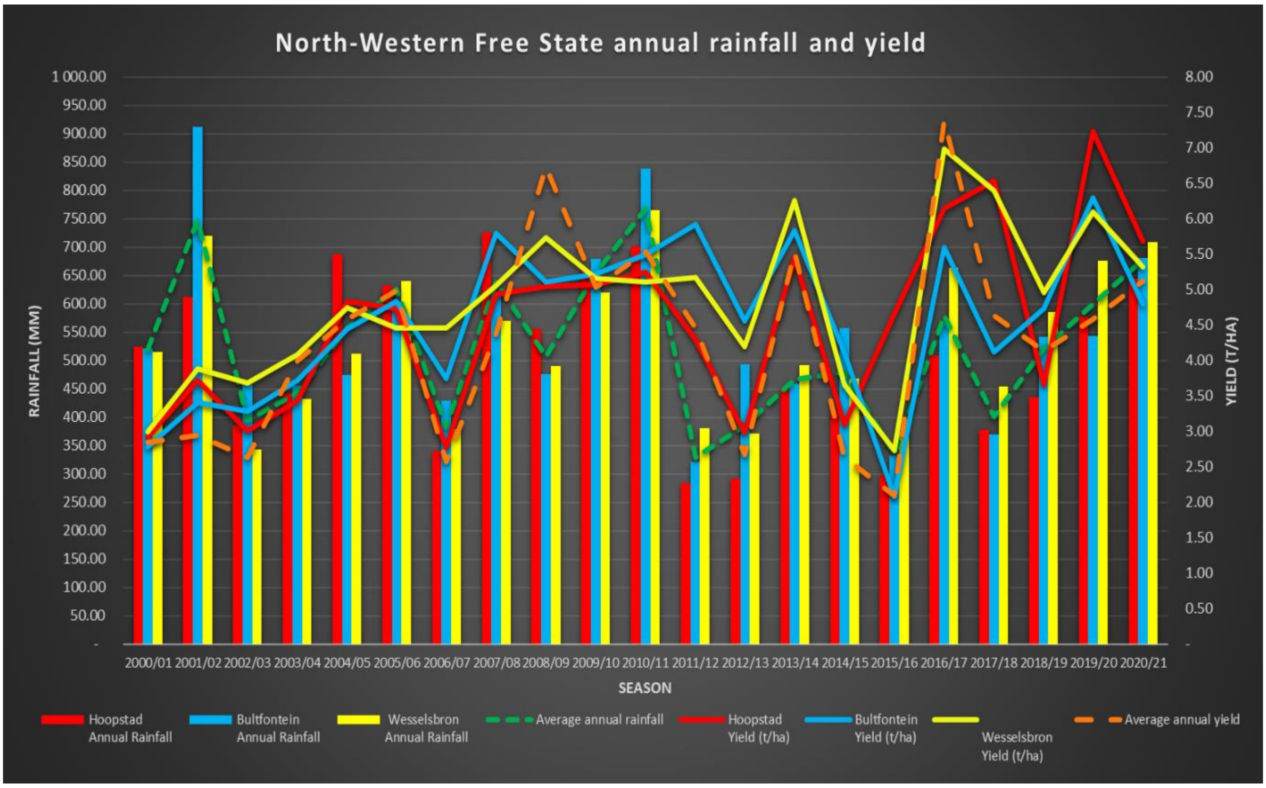

Figure 4.1: Average rainfall per season (July till June) in the North-Western Free State
Source: Compiled by author

Figure 4.1 indicates the amount of rain that falls on average during the season, which runs from July to June at the three different weather stations. The average rainfall for the North-Western Free State over the 20 years is 528 mm per year. Figure 4.1 indicates that above-average rainfall also led to higher maize yields and below-average rainfall also leads to lower yields. Above average rainfall was experienced during the 2009/10, 2010/11, 2016/17 season, and also 2019/20 and 2020/21 season. During the 2006/07, 2012/13, 2015/16 and 2018/19, below average yields were achieved.

4.2.2 Average yield per hectare per season

Figure 4.1 shows a high yield variability. These data are further analysed and are presented in table 4.1, which indicates the yields achieved for twenty-one years in the North-Western Free State.

Table 4.1: Average Yield of maize tons per hectare in the North-Western Free State from 2000/01 to 2020/21

	North-Western Free State Average Yield (t/ha)	Bultfontein Average Yield (t/ha)	Hoopstad Average Yield (t/ha)	Wesselsbron Average Yield (t/ha)
2000/01	3.79	2.78	2.92	3.00
2001/02	3.83	3.41	3.72	3.89
2002/03	3.88	3.29	3.01	3.69
2003/04	4.38	3.72	3.44	4.08
2004/05	4.55	4.45	4.84	4.75
2005/06	5.01	4.83	4.73	4.46
2006/07	4.02	3.75	2.77	4.46
2007/08	5.85	5.80	4.93	5.06
2008/09	5.90	5.11	5.05	5.74
2009/10	5.57	5.22	5.07	5.16
2010/11	5.63	5.50	5.25	5.11
2011/12	5.50	5.92	4.30	5.17
2012/13	4.03	4.56	2.99	4.20
2013/14	6.32	5.83	5.46	6.26
2014/15	4.16	4.11	3.10	3.66
2015/16	3.37	2.08	4.66	2.73
2016/17	6.84	5.60	6.15	6.98
2017/18	5.70	4.12	6.53	6.40
2018/19	5.21	4.74	3.66	4.96
2019/20	6.83	6.30	7.23	6.10
2020/21	5.81	4.80	5.69	5.32
Average	5.06			
Standard Deviation	1.00			

Source: Compiled by author

The average yield for the North-Western Free State is 5.06 t/ha, with a standard deviation of 1.00. 1t/ha may not be seen as a prominent level of variability but in tons per hectare, it can explain the difference between overall profits or losses. The changing levels of variability can potentially be explained by two factors.

According to Viljoen and Chetty (2011), first-generation commercial genetically modified (GM) maize has been grown in South Africa since 1997. The initial uptake of GM maize was slow but changed quickly when the farmers obtained much higher average yields. South African maize farmers also planted high volumes of biotech crops due to a successful export drive. In 2006, 44 per cent of all white maize in South Africa adopted biotech crops technology; in 2007, this number increased to 62 per cent (James, 2011). The higher number of better crop technology maize can be seen in the improved yields from the 2006/07 season.

As mentioned in Section 4.2.1, the effect of biotech crops can be seen in 2006. In terms of global commercial GM production in 2008, South Africa ranked eighth (James, 2009). This can be seen in the data above on how the average maize yield in Northern Free State has improved since the 2006/07 season. Despite the general increasing trend in yield, one observes that the average yield per ha between 2014/15 and 2015/16 is far below average. This can be attributed to the drought experienced through this period and lower-than-average annual rainfall (as depicted by Figure 4.1).

4.2.3 Correlations between yield and different rainfall months

In the first step to exploring the potential relationship between maize yield and rainfall, correlation coefficients are calculated, and graphical representations of the data are provided. Correlation coefficients can be used to determine the degree to which maize yields and rainfall are linked. The longer the period that farmers hedge themselves against adverse rain (time is a variable that influences the premium of an option – the longer the time to maturity) the more expensive the option premium. It is, therefore, important to determine which period has the greatest impact on yields and only purchase a rainfall option during the critical period. Not only does the distribution of rain throughout the growing season has a significant impact on yield, but the soil's water holding capacity, infiltration capacity, evaporation capacity, and drainage capacity can all have a significant impact on the efficient use and utilization of rainwater - and, ultimately, optimal grain production. This study only focuses on rainfall because many of these factors that have an impact on production is area specific and also differ from farm to farm. The correlation matrix below provides a first indication of whether or not there are statistically significant correlations between the variables employed in this study.

Table 4.2: Correlation matrix and probabilities for average yield and rainfall of maize between different periods

		Yield	Rainfall (November – December)	Rainfall (January – February)	Rainfall (January – March)	Rainfall (April – June)
Yield	Correlation	1.000000				
	Probability	-----				
Rainfall (November – December)	Correlation	-0.022751	1.000000			
	Probability	0.8595	-----			
Rainfall (January – February)	Correlation	0.647853	0.089448	1.000000		
	Probability	0.0000	0.4857	-----		
Rainfall (January – March)	Correlation	0.574760	0.092760	0.940095	1.000000	
	Probability	0.0000	0.4696	0.0000	-----	
Rainfall (April – June)	Correlation	-0.132652	-0.203103	-0.163903	-0.151995	1.000000
	Probability	0.3000	0.1104	0.1993	0.2344	-----

Source: Compiled by author

As mentioned before, when the correlation coefficient is -1, it suggests that even if the rainfall is lower than projected, the yield will always be higher. A correlation coefficient of 0, on the other hand, indicates that maize production and rainfall have no relationship. Movements in the same direction are represented by a very positive, statistically significant correlation value up to a maximum of 1.

Table 4.2 indicate that there is a negative correlation of -0.02275 during the planting season from November to December. This is close to 0, indicating no meaningful relationship between rainfall and yield during this period. The estimated correlation coefficient estimated for this period is also the least statistically significant (at an 86% level). It will not benefit farmers to hedge during this period because of the negative correlation coefficient and lack of statistical significance. This negative sign, however, makes sense because if it doesn't rain during this period, farmers will not plant maize and there would be no harvest to hedge against unpredictable rainfall. It also indicates if the fields are too wet, farmers will also not take the risk because the crop will be waterlogged, or they won't be able to enter the fields with the necessary machinery and equipment to plant.

From January to February there is a highly positive relationship between yield and rainfall (0.64785). This indicates the most crucial time for crops to secure high yields is when adequate rain is received. This is interesting as it represents only a two-month period of the total of 110 days needed for a maize plant to produce maize (see Figure 3.2). It confirms the sensitivity of maize plants towards adverse weather during this period. For January until March, there is a positive correlation between average rainfall and average maize yield (0.574760). During this period, the kernels of the maize plant will form. The correlation further makes sense as it represents more than half the time needed for maize plants to produce maize. Correlations for both these periods are statistically significant at a 1% level.

April to June indicates a negative correlation coefficient of -0.13265, indicating no statistically significant relationship. This is confirmed by the fact that the maize plant starts to dry off and is not dependent on rainfall during this stage.

With the positive correlation relationships between yield and rainfall during January and March, the higher relationship between January and February potentially indicates that it will benefit a farmer more to only hedge during these two months as this period is not only the most crucial for kernel forming, but is also a shorter period to hedge, making the rainfall option more affordable.

In the next few paragraphs, graphical representations of the data help to shed lighter on the calculated correlation coefficients reported above.

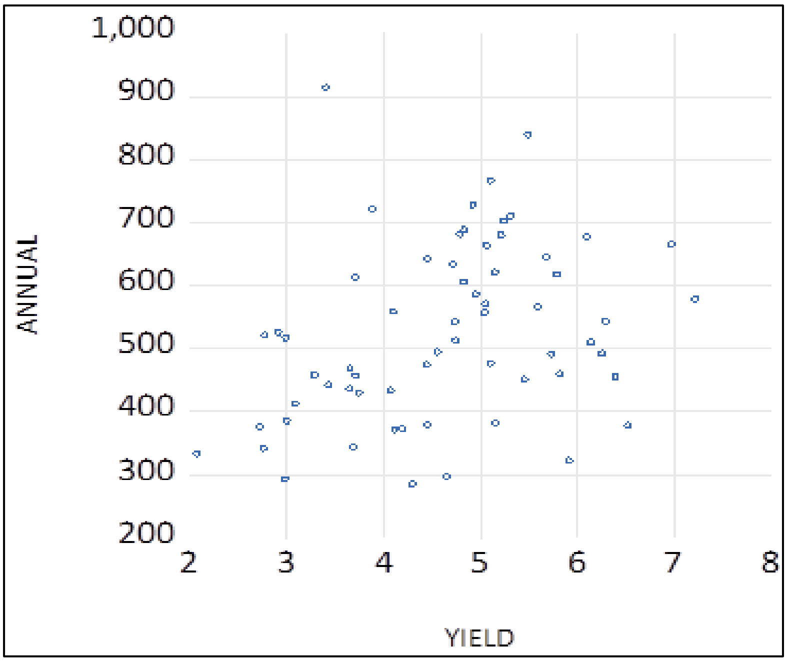

Figure 4.2: A scatter plot of the total annual rainfall vs maize yield for the North-Western Free State.
Source: Author's representation of data using EViews 12

Figure 4.2 implies a positive relationship between the total annual rainfall and the yield. As mentioned before, the average rainfall for the North-Western Free State region is 528 mm per year. With a few outliers, it is evident that above-average rainfall leads to higher yields, whereas below-average rainfall leads to lower yields. Figure 4.2 indicates that above-average rainfall can also lead to lower yields, like the outlier of more than 900mm of rain only corresponds with 3.5t/ha of maize.

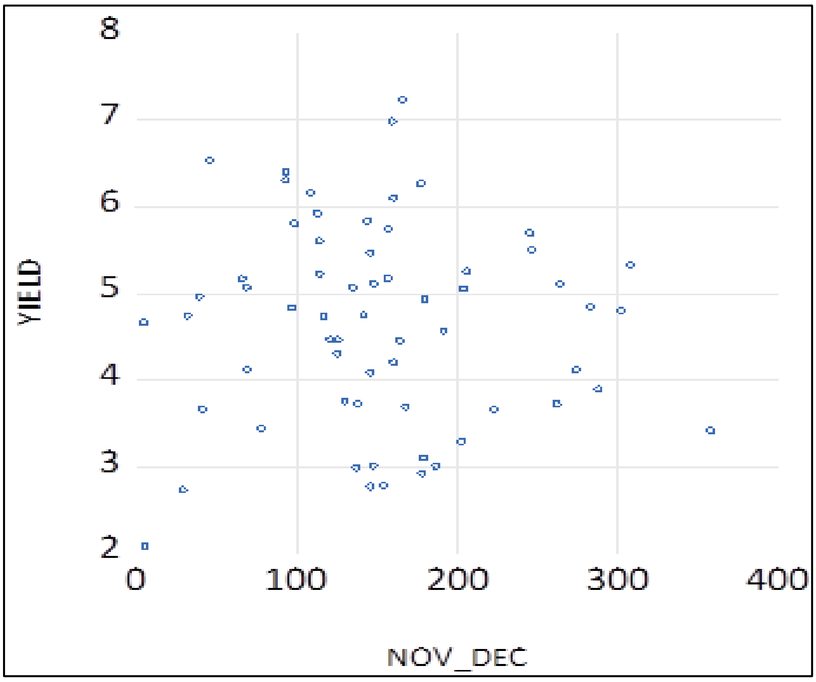

Figure 4.3: A scatter plot of the total annual rainfall from November to December vs yield.
Source: Author's representation of data using EViews 12

The interpretation of Figure 4.3 corresponds with the calculations in the correlation matrix of Table 4.2. There is no clear relationship between maize yield and the average rainfall during the planting season of November to December. This can be attributed to different reasons, for instance, that no rain during the planting season means no planting. Yield is not only affected by weather after planting, but also by the ability to plant. If adverse weather occurred during the planting season, fewer hectares will be planted which can result in lower yields.

Another reason for the unclear relationship can be that farmers can plant with a little amount of rain due to the ability of water table soil when the previous season had good early rainfall early in the season, like in September. Figure 4.4 below indicates the scatter plot of yield and rainfall during the period from January to March.

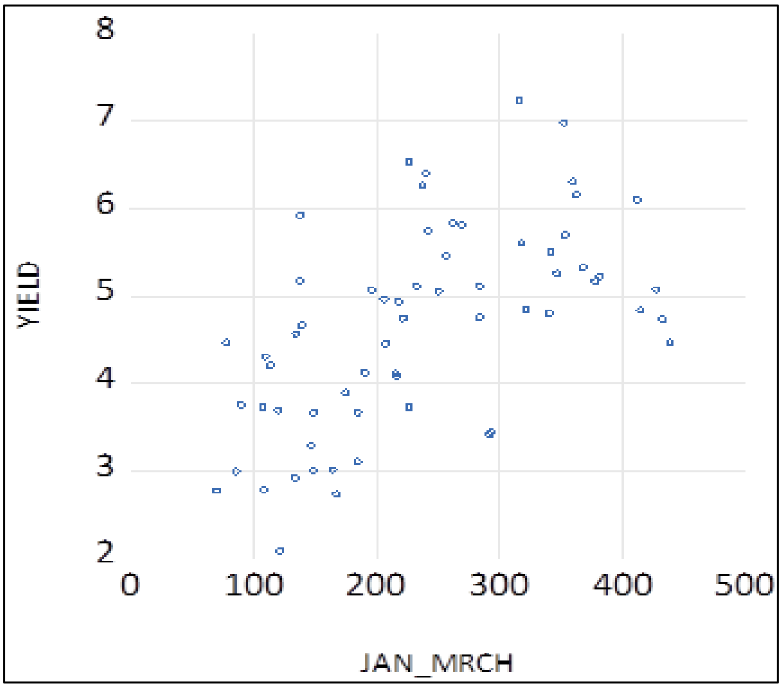

Figure 4.4: A scatter plot of the series' annual average rainfall from January to March vs yield
Source: Author's representation of data using EViews 12

In Figure 4.4, a clear positive relationship exists between average annual rainfall during the critical kernel stages that run from January to March. The higher the rainfall during this period, the better the maize yield. This corresponds with Table 4.4 where the correlation matrix indicates that there exists a statistically significant relationship between yield and this period of 0.51738. A turning point in realised yields when rainfall increases above 300mm also seems evident from Figure 4.4. This shows that maize yield is also sensitive to too much rain during this period. The crop can be damaged and waterlogged if too much rain occurs during this period, this emphasises the importance of the right amount of rain and the timing of the rainfall. This is also confirmed by Ikisan (2022) (see section 3.2.1).

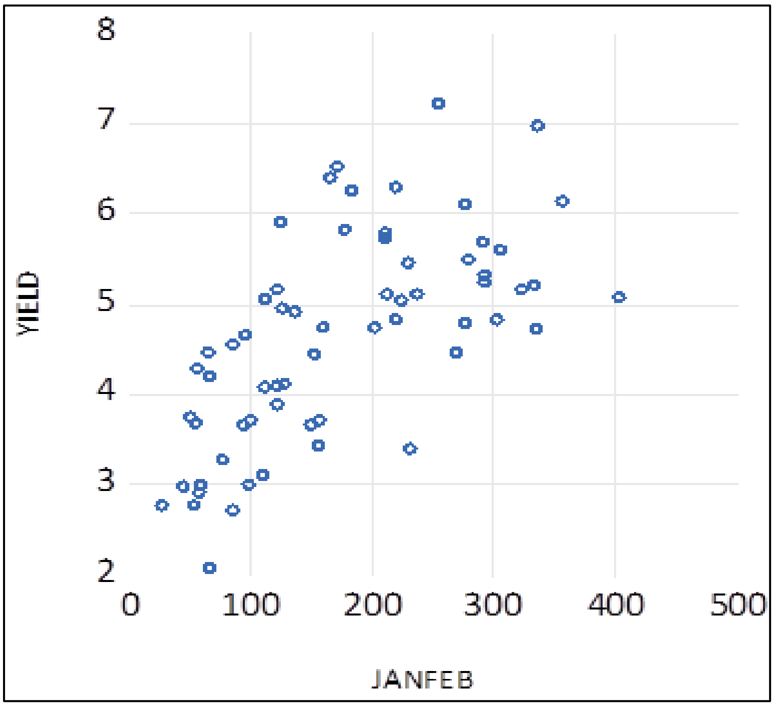

Figure 4.5: A scatter plot of the average rainfall from January to February vs yield.
Source: Author's representation of data using EViews 12

Figure 4.5 indicates a positive relationship between yield and rainfall from January to February. During this period, the maize plant will typically start pollination for five to ten days and moisture is critical during this period. At this period, maize is sensitive to stress. At the cob tip, stress can result in kernel abortion, and water deficit can cause wilted leaves, which can result in a yield loss of up to 7% each day (Pringle, 2017). The higher the rainfall the better the yields. Figure 4.5 corresponds with Table 4.3 where this period has the highest correlation with yield. In Table 4.2 the estimated coefficient of this period is also statistically significant at a 1% level of significance see Section 4.2.4.

The above provides compelling arguments that rainfall from January to February is the most important time to hedge against adverse rainfall to receive good yields in the North-Western Free State – while Figure 4.4 indicates that the maize yield should receive less rain during the period April to June when the kernel is already formed. During this stage, the yield is already determined, and weather only influences crop quality. This observed graphical relationship will be further explored in the regression analysis of section 4.2.4.

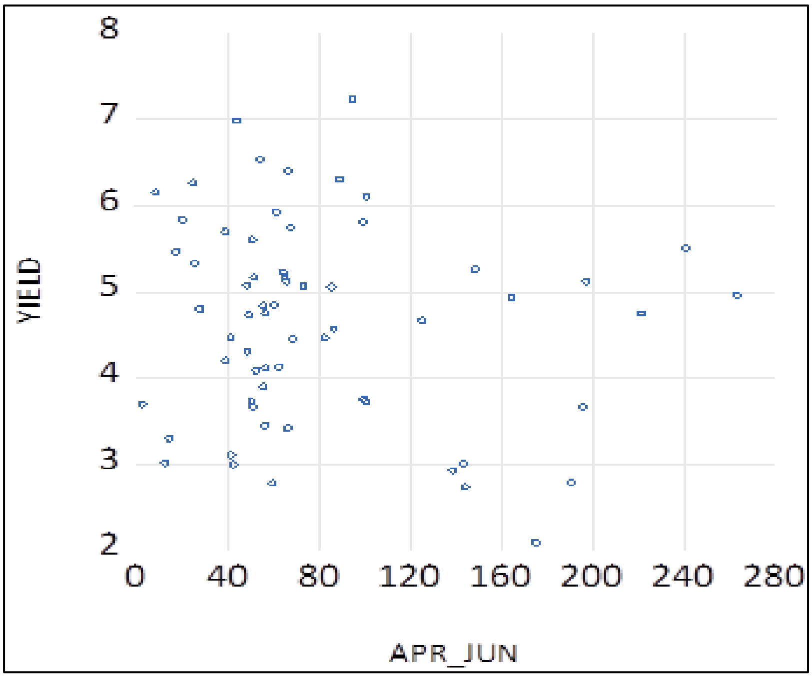

Figure 4.6: A scatter plot of the average rainfall from April to June vs yield.
Source: Author's representation of data using EViews 12

The importance of rainfall derivatives for maize producers in South Africa is demonstrated by the positive significant relationship between yield and rainfall between January and March, and even more so for the period between January and February. Yield risk will be reduced significantly if farmers can hedge themselves from severe rainfall patterns during the critical kernel-forming phases of maize.

To conclude, it is noted that the period from January to February is the most important time for a maize plant to receive rain to deliver good yields. In the next section, the focus will move to the profitability of the crop to know how much yield is needed for a farmer at harvest to be financially profitable.

4.2.4 Average rainfall data during different periods

A multiple OLS regression is subsequently estimated to identify if any/or which of the rainfall periods have a significant relationship with maize yield (as dependent variable). The regression model assumes that the values for yield are produced by the values of the variables. Probability is examined to determine whether the relationship between yield and the variables is statistically significant.

To identify which variables are a good fit for the regression, R^2 is examined. R^2 represents the percentage of variance that is explained by an independent variable in the regression. The norm for R^2 values is between zero and one, a variable with an R^2 value closer to one is ideal (Moore *et al*., 2019).

This means that a higher percentage of the variance is explained by this variable and that the variable is a good fit in the regression. In this study the adjusted R^2 values are used because adding more independent variables to the regression increases the R^2 value, making it an inaccurate measure (Asteriou & Hall, 2011).

It's important to remember that maize yield is affected not only by rainfall but also by the overall climate. Temperature, for example, might harm yield. This study mainly examines the association between maize yield and rainfall. Determining when rainfall has the greatest impact on yields will help determine the period for farmers when it is the most important to hedge against volatile rainfall. Although temperature does affect maize yield, the study only focussed on rainfall because temperature derivatives, in the form of heating degree days and cooling degree days, are already traded internationally. Temperature related derivatives were traded OTC in South Africa, but then the uptake was only in the game industry and not amongst maize farmers.

Table 4.3 summarises results of multiple regressions estimated on rainfall for the three weather stations. Data for the three stations recorded over the 21-year period are pooled into one sample as basis for pooled regressions. Yield per hectare serves as dependent variable. As explanatory variables, rainfall is divided into different growing periods during the season: November to December (NovDec) when planting starts, January to March (JanMrch), which is the critical stage and the kernel forming stage, and April to June (AprJun) after the kernel is formed for the period 2000/01 to 2020/21. In order to shorten the period to be hedged, JanMrch is replaced in the specification with the variable JanFeb, rainfall for January to February. Quadratic versions of the rainfall periods are also included to test for relationships that are not only linear. A dummy variable (Dum2006), with a value of 1 from 2006 onwards and a value of 0 before 2006, is included to capture the effect of new crop technologies on historical yields. The results of the multiple regression are captured in Table 4.3 below.

Table 4.3: Multiple regressions explaining maize yield

	Only yield and three different periods included		Turning points of the different periods included		February to March and Dummy of 2006 included	
	Equation 1		Equation 2		Equation 3	
	Variables in levels					
	Estimated coefficients	**Probability**	**Estimated coefficients**	**Probability**	**Estimated coefficients**	**Probability**
C	3.411098	0.0000	0.697020	0.4497	0.024577	0.1318
JanFeb					-4.43E-05	0.0000
JanFeb^2					-0.001712	0.0000
Janmrch	0.006487	0.0000	0.024227	0.0002	3.04E-06	0.7519
JanMrch^2			-3.46E-05	0.0043	0.011819	0.8872
AprJun	-0.001255	0.5622	0.001489	0.8353	-3.80E-05	0.0049
AprJun^2			-8.35E-06	0.7695	0.902244	0.0016
NovDec	-0.001348	0.4151	0.009615	0.0767	0.863515	0.0000
NovDec^2			-3.46E-05	0.0260	0.024577	0.1318
Dum2006					-4.43E-05	0.0000
R^2	0.339985		0.463410		0.700464	
Obs (n)	63		63		63	
	Variables in logs					
	Estimated coefficients	**Probability**	**Estimated coefficients**	**Probability**	**Estimated coefficients**	**Probability**
C	-0.388609	0.3320	-11.11206	0.4560	-15.80843	0.2058
JanFeb					0.641344	0.8369
JanFeb^2					0.058390	0.8640
JanMrch	0.337626	0.0000	3.349526	0.5434	4.999709	0.4154
JanMrch^2			-0.185316	0.7230	-0.485387	0.4226
AprJun	-0.006275	0.8611	0.387879	0.6323	-0.217941	0.7461
AprJun^2			-0.054283	0.6135	0.019177	0.8298
NovDec	-0.021701	0.5569	1.346271	0.1366	1.334741	0.0646
NovDec^2			-0.166544	0.1335	-0.147300	0.0962
Dum2006					0.937677	0.0004
R^2	0.77200		0.391184		0.638531	
Obs (n)	63		63		63	

Source: Compiled by author

As part of the specification of the above equations, it was also considered to include rainfall figures from the previous year. The estimated coefficient was, however, not statistically significant, therefore, it is not reflected as part of the results. When looking at the regression between yield and the three different periods that are included, we can see that the value of R^2 is 0.339985, meaning that only 33% of the variation in yield is explained. This is not ideal and not a good fit for the regression. Comparing the three different periods, only January to February is statistically significant at a 5% level of significance. The periods from April to June and November to December are statistically insignificant.

When turning points are included in the multiple regression, the period from January to March is still statistically significant at a 5% level of significance. The period of January to March turning point (JanMrch^2) is also statistically significant at a 5% level of significance. When the turning point is included in the regression, the R^2 also improved to 0.463410, meaning that 46% of the variance is explained by the variables included in the regression.

The regression looks better when considering the inclusion of the dummy variable of 2006, the use of biotech crops showing a significant increase in South Africa, and a new period of January and February. The R^2 improved with a value of 0.700464, meaning that 70% of the variance is explained by the variables included in the regression. The period January to February and its turning point (JanFeb^2) are highly statistically significant at a 1% significance level. The period November to December and the dummy variable included is also statistically significant at a 1% significance level.

The next step will look at correlations between yield and rainfall to find the best period for farmers to hedge against adverse rainfall.

4.2.5 Crop profitability

Crop profitability analysis is important to establish if maize is a profitable crop for the North-Western Free State. Table 4.4 below indicates the historical input and producer prices of maize for each season over the past 20 years (Grain SA, 2022).

Table 4.4: Historical data on maize profitability in the North-Western Free State

Season	Total variable cost	Total capital cost	Total cost (per/ha)	Yield (ton/ha)	Cost (R/ton)	Producer price (R/ton)	Producer price (p/ha)	Profit or Loss (p/ha)	Profit or Loss (p/ton)
2000/01	R1 667.82	R539.03	R2 206.85	3.79	R582.28	R719.23	R2 725.88	R519.03	R136.95
2001/02	R2 075.82	R580.70	R2 656.52	3.83	R693.61	R1 420.30	R5 439.75	R2 783.23	R726.69
2002/03	R2 468.68	R544.95	R3 013.63	3.88	R776.71	R1 006.45	R3 905.03	R891.40	R229.74
2003/04	R2 777.53	R481.45	R3 258.98	4.38	R744.06	R923.09	R4 043.13	R784.15	R179.03
2004/05	R2 727.21	R492.15	R3 219.36	4.55	R707.78	R619.16	R2 816.25	-R403.11	-R88.62
2005/06	R3 030.71	R500.61	R3 531.32	5.01	R704.52	R1 069.26	R5 359.56	R1 828.24	R364.74
2006/07	R3 160.95	R500.61	R3 661.56	4.02	R910.04	R1 502.91	R6 046.96	R2 385.40	R592.87
2007/08	R4 559.38	R528.46	R5 087.84	5.85	R869.72	R1 632.83	R9 552.06	R4 464.22	R763.11
2008/09	R4 994.22	R723.56	R5 717.78	5.90	R969.11	R1 347.70	R7 951.43	R2 233.65	R378.59
2009/10	R4 710.52	R838.08	R5 548.60	5.57	R996.16	R1 041.66	R5 802.05	R253.44	R45.50
2010/11	R5 265.47	R874.64	R6 140.11	5.63	R1 090.61	R1 559.88	R8 782.12	R2 642.01	R469.27
2011/12	R5 928.63	R661.44	R6 590.07	5.50	R1 198.19	R2 057.52	R11 316.36	R4 726.29	R859.33
2012/13	R6 070.65	R751.03	R6 821.68	4.03	R1 692.73	R2 035.79	R8 204.23	R1 382.55	R343.06
2013/14	R6 779.94	R863.81	R7 643.75	6.32	R1 209.45	R1 802.59	R11 392.37	R3 748.62	R593.14
2014/15	R7 050.85	R908.83	R7 959.68	4.16	R1 913.39	R2 311.46	R9 615.67	R1 655.99	R398.07
2015/16	R7 340.18	R973.68	R8 313.86	3.37	R2 467.02	R2 290.00	R7 717.30	-R596.56	-R177.02
2016/17	R7 312.78	R1 063.27	R8 376.05	6.84	R1 224.57	R1 599.00	R10 937.16	R2 561.11	R374.43
2017/18	R8 097.73	R954.73	R9 052.46	5.70	R1 588.15	R1 847.00	R10 527.90	R1 475.44	R258.85
2018/19	R8 232.47	R1 075.40	R9 307.87	5.21	R1 786.54	R2 316.58	R12 069.38	R2 761.51	R530.04
2019/20	R8 439.77	R1 025.36	R9 465.14	6.83	R1 385.82	R2 154.50	R14 715.24	R5 250.10	R768.68
2020/21	R9 123.58	R910.91	R10 034.49	5.81	R1 727.11	R2 751.88	R15 988.42	R5 953.93	R1 024.77

Source: Grain SA (2022)

Table 4.4 indicates that the total cost (total variable cost + total capital cost) of maize has increased each year. The reason is higher input costs and the rise of inflation. The yield of maize per hectare has also been improving. This can be attributed to better farming practices and technology, as mentioned before. It is also clear that 2004/05 and 2015/16 were not profitable seasons for maize cultivation in this region. This corresponds with Figure 4.1, where it is clear that recorded rainfall was below the average for the region by 528mm per year.

Table 4.5: Summary of maize costs

Season	Total cost per hectare	Profit/Loss Per ha:	Yield (ton/ha)	Yield as a percentage of input cost	Yield as a percentage of Profit	Price as a percentage of input costs
2000/01	R2 206.85	R 519.03	3.79	0.17%	0.73%	33%
2001/02	R2 656.52	R2 783.23	3.83	0.14%	0.14%	53%
2002/03	R3 013.63	R 891.40	3.88	0.13%	0.44%	33%
2003/04	R3 258.98	R 784.15	4.38	0.13%	0.56%	28%
2004/05	R3 219.36	-R 403.11	4.55	0.14%	-1.13%	19%
2005/06	R3 531.32	R1 828.24	5.01	0.14%	0.27%	30%
2006/07	R3 661.56	R2 385.40	4.02	0.11%	0.17%	41%
2007/08	R5 087.84	R4 464.22	5.85	0.11%	0.13%	32%
2008/09	R5 717.78	R2 233.65	5.90	0.10%	0.26%	24%
2009/10	R5 548.60	R 253.44	5.57	0.10%	2.20%	19%
2010/11	R6 140.11	R2 642.01	5.63	0.09%	0.21%	25%
2011/12	R6 590.07	R4 726.29	5.50	0.08%	0.12%	31%
2012/13	R6 821.68	R1 382.55	4.03	0.06%	0.29%	30%
2013/14	R7 643.75	R3 748.62	6.32	0.08%	0.17%	24%
2014/15	R7 959.68	R1 655.99	4.16	0.05%	0.25%	29%
2015/16	R8 313.86	-R 596.56	3.37	0.04%	-0.56%	28%
2016/17	R8 376.05	R2 561.11	6.84	0.08%	0.27%	19%
2017/18	R9 052.46	R1 475.44	5.70	0.06%	0.39%	20%
2018/19	R9 307.87	R2 761.51	5.21	0.06%	0.19%	25%
2019/20	R9 465.14	R5 250.10	6.83	0.07%	0.13%	23%
2020/21	R10 034.49	R5 953.93	5.81	0.06%	0.10%	27%

Compiled by author

Table 4.5 summarizes the costs of maize compared to yield and as a percentage of input cost. Although yields improved over the years, the percentage of yield on input costs decreased due to the higher input costs. Table 4.5 also emphasizes the cost-price-squeeze farmers have to face each season, it is seen on how the yield on profit percentage decreased over the years and it is clear that higher yields are needed to farm in a profitable way. Price as a percentage of input costs increased the last five seasons as a result of higher producer prices but also higher input costs.

In 2004/05, biotech crops were not yet something farmers considered and if they made use of these technologies, it could've prevented financial losses because during this season, 558mm of rainfall were achieved, which was above the average rainfall of 528mm for the area. The loss in 2015/16 is attributed to the below-average rainfall during that season. The drought caused crops to suffer under severe pressure and caused stress leading to low yields, making maize unprofitable during that season. It is also clear that in the last three years, higher producer prices, better rainfall and improved yields led to higher profits.

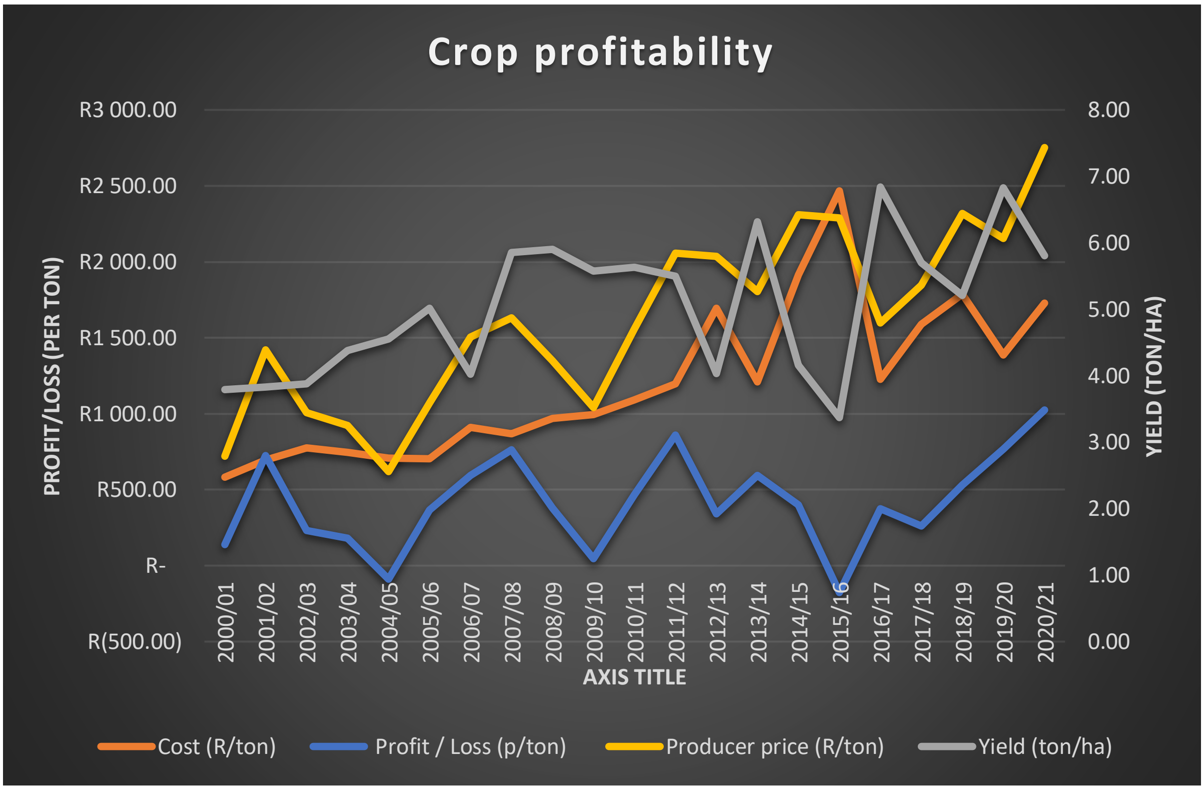

Figure 4.7: Crop profitability graph in the North-Western Free State
Source: Compiled by author

Figure 4.7 indicates the importance of good yields. The last decade's increases in input costs confirm the fact that maize is less profitable when yields are low. The graph shows that when yields are low, profits are low, as we expected, and vice versa. The graph also indicates that in the last five seasons, except for the 2016/17 season, profitability of the crop started to increase as the producer price increased; the yield also increased during that period (see Table 4.5). Table 4.5 and Figure 4.7 emphasizes how important it is to mitigate yield risk due to the cost-price-squeeze that farmers experience.

4.2.6 Sensitivity analysis for determining profitable yield for maize

In the previous sections, the relationship between yield and rainfall, and profitability levels was analysed. The focus now shifts to price-yield sensitivity analysis to determine the break-even price and yield for maize in the North-Western Free State. This will determine the minimum yield that farmers need to harvest with the current input cost at hand to know if maize will be a profitable crop option. After the specific yield is determined, the corresponding required rainfall from January to February will be calculated based on the reported regression results.

To determine the ideal yield necessary for maize to be a profitable crop, data will only be analysed from 2006, when biotech crops were introduced to improve yields.

Table 4.6: Profit on input cost margins

Season	Total cost (per/ha)	Yield (ton/ ha)	Profit or Loss (p/ha)	Profit on input costs
2006/07	R3 661.56	4.02	R2 380.14	65%
2007/08	R5 087.84	5.85	R4 464.22	88%
2008/09	R5 717.78	5.9	R2 233.65	39%
2009/10	R5 548.60	5.57	R253.45	5%
2010/11	R6 140.11	5.63	R2 642.01	43%
2011/12	R6 590.07	5.5	R4 726.29	72%
2012/13	R6 821.68	4.03	R1 382.55	20%
2013/14	R7 643.75	6.32	R3 748.62	49%
2014/15	R7 959.68	4.16	R1 655.99	21%
2015/16	R8 313.86	3.37	-R596.56	-7%
2016/17	R8 376.05	6.84	R2 561.11	31%
2017/18	R9 052.46	5.7	R1 475.44	16%
2018/19	R9 307.87	5.21	R2 761.51	30%
2019/20	R9 465.13	6.83	R5 250.11	55%
2020/21	R10 034.49	5.81	R5 953.93	59%
Average	R7 314.73	5.38		39%
Standard Deviation	R1 784.84	1.00		25%

Compiled by author

Table 4.6 indicates that farmers in the North-Western Free State, in the water table soil area, have an average profit margin of 39 per cent on input costs. For a farmer to be able to hedge against these numbers, it is important to find the minimum yield required to reach a profit margin of 39 per cent on input cost. The farmer wants to increase his profit margin on input costs of 39% because that is what the area offers based on historical data; this can be considered the break-even price because this area has high potential soil. If a yield of 5.38t/ha is harvested, a profit margin of 39% on input costs is achieved. 5.38t/ha is the critical yield level, which is ideal for the area. (see Table 4.6).

With the average yield of 5.38t/ha, YaR will help to determine the minimum that a farmer can harvest in this area to still be able to achieve a 39 per cent profit on input cost. YaR measures the worst expected loss over a given horizon under normal market conditions at a given level of confidence. Historical YaR will be used because the historical method simply re-organizes actual historical returns, putting them in order from worst to best. It then assumes that history will repeat itself, from a risk perspective.

Table 4.7: Historical Value-at-Risk method

YaR confidence interval	Percentage of profit on input cost	Impact on average t/ha
YaR 90%	9.3%	4.88
YaR 95%	1.04%	5.32
YaR 97%	-2.24%	5.25
YaR 99%	-5.53%	5.08

Compiled by author

Using the historical YaR method, Table 4.7 indicates the different confidence levels of 90%, 95%, 97% and 99%, at which a farmer needs to harvest to still be able to achieve 39 per cent profit on input cost. Table 4.7 indicates that at a 99 percent confidence level, the minimum that a farmer can harvest with a -5.53 percent deviation is 5.08t/ha in order to receive a 39 percent profit on input costs. It is critical to not have a greater deviation of 5.53 per cent of the average profit on input cost of 39 per cent.

The next step considers the amount of rainfall that will affect 5.08t/ha.

4.2.7 Rainfall levels that impact yield

Section 4.2.4 revealed that the most significant period of rainfall impacting on yield, is the two-month period of January and February. It was noticed that monthly rainfall is not always the best answer, but a better proxy would be the timing and the amount of rainfall. As basis risk still occurs in South Africa, a problem is also that the number of independent weather stations is limited. The onset and the time difference of the rainfall happens to fall outside the scope of this study and can be included in further studies.

In this stage, the minimum and maximum amount of rain needed to harvest 5.08t/ha will be determined. It is also known that the amount and timing can affect the quality of the grain as seen in the past, it is not a fixed measure and falls outside the scope of this study.

It is also important to note that the previous seasons' total annual rainfall is ignored in the empirical study because it was found to be statistically insignificant; therefore, it is not reflected as part of the results. It is, however, conceded that the previous seasons' rainfall can have an impact on this season's yield ability because it affects the water table soil area.

Equation 3 in Table 4.3 was used to forecast the expected yield for varying levels of rainfall for the period January and February. This is needed to determine the required rainfall for January to February to harvest 5.0t/ha and still be able to make a profit of 39 per cent on input cost. The table below reports forecasted yield at different combined rainfall levels for January and February. The average rainfall for the other two periods included in equation 3, AprJun and NovDec, are used in the forecast.

Table 4.8: Yield forecast at different levels of rainfall

Yield (t/ha)	January to February rainfall (mm)
5.510419	**175.14**
4.80535	115
4.876182	120
4.9448	125
5.011202	130
5.07539	135
5.137362	140
5.19712	145
5.254662	150
5.30999	155
5.363102	160
5.414	165
5.462682	170
5.50915	175
5.553402	180
5.59544	185
5.635262	190
5.67287	195
5.708262	200
5.74144	205
5.772402	210
5.80115	215
5.827682	220
5.852	225
5.874102	230
5.89399	235
5.911662	240
5.92712	245
5.940362	250
5.95139	255
5.960202	260
5.9668	265
5.971182	270

5.97335	275
5.973302	280
5.97104	285
5.966562	290
5.95987	295
5.950962	300
5.93984	305
5.926502	310
5.91095	315
5.893182	320
5.8732	325
5.851002	330
5.82659	335
5.799962	340
5.77112	345
5.740062	350
5.70679	355
5.671302	360
5.6336	365
5.593682	370
5.55155	375
5.507202	380
5.46064	385
5.411862	390
5.36087	395
5.307662	400
5.25224	405
5.194602	410
5.13475	415
5.072682	420
5.0084	425
4.941902	430
4.87319	435
4.802262	440
4.72912	445
4.653762	450
4.57619	455
4.496402	460
4.4144	465
4.330182	470
4.24375	475
4.155102	480
4.06424	485
3.971162	490
3.87587	495
3.778362	500

Compiled by author

The first row of the table represents an average rainfall for January and February of 175mm which results in a yield of 5.5t/ha. If we need to harvest 5.08t/ha to make 39 per cent profit on input cost to be financially on average and to use the area's potential outfall, the minimum rain for January and February is 135mm, and if it's more than 420, the crops will be waterlogged. The optimum rainfall level for January and February to receive the highest level of yields is 275mm.

These calculated rainfall levels now provide the values needed to write an option to see if it is financially more feasible than other insurance products available in the agricultural sector.

4.2.8 Pricing rainfall options

Crop failure frequently results in losses for farmers. The unpredictable nature of weather occurrences has an impact on the success or failure of the harvest. The primary benefit of weather derivatives over conventional insurance is that damage assessment is not necessary (Leblois & Quirion, 2013). The significant association between climate events and crop losses justifies the use of climate indices in agricultural insurance. The Historical Burn Analysis approach is one way to compute climate index insurance (Taib & Benth, 2012). Farmers are required to pay a premium for agricultural insurance each harvest season. The Black-Scholes formula can be used to determine the premium based on the rainfall index.

Similar to the Black-Scholes method for pricing European-style equity options and related derivatives, there is no established model for valuing weather derivatives. This is because the weather derivative's underlying asset cannot be traded, which violates several important tenets of the Black-Scholes Model.

The main option-pricing model, Black-Scholes-Merton, is founded on the idea of continual hedging (Botos & Ciumas, 2012). This is effective when pricing options on fungible assets can be exchanged on the spot market, such as currencies, equities, commodities, and others.

Black-Scholes, as pricing model, uses six factors, including volatility, option type, underlying stock price, time to maturity, strike price, and the risk-free rate, to calculate the fair price or theoretical value for a call or put option. The model is used to determine the price of a European call option, which simply means that the option can only be exercised on the expiration date. The Black Scholes formula can therefore be used to price weather derivatives as the option will only be exercised at the end of the indexed period.

The European type options determined by the Black Scholes formula according to Ariyanti, Riaman, and Irianingsih (2020) are as follows:

$$P = K\, e^{-r\,T} N(-d_2) - S_0 N(-d_1) \tag{4.1}$$

With P as the option price, S_0 is the initial stock price, K is the option strike price, r is the risk-free interest rate, σ_T is the standard deviation of the stock price, T is time until maturity, $N(-d_1)$ is the cumulative density function of the normal distribution of d_1, $N(-d_1)$ is the cumulative density function of the normal distribution of D_2.

In this study, P is option premium price, S_0 is the average rainfall achieved over the period from January to February, which will be the index value, and K is the option strike amount, which is the rainfall amount needed in January and February to harvest a yield of 5.08t/ha. r is the average risk-free interest rate over twenty years, which is 7.37% calculated from historical SARB data. The risk-free rate used is the 91-day treasury bill rate. σ_T is the annualized volatility of rainfall in January to February over the period, which is 35 per cent, T is time until maturity, which will be assumed that the options will be bought at the start of planting, which will be for three months starting in December, $N(-d_1)$is the cumulative density function of the normal distribution of d_1, $N(-d_1)$ is the cumulative density function of the normal distribution of D_2.

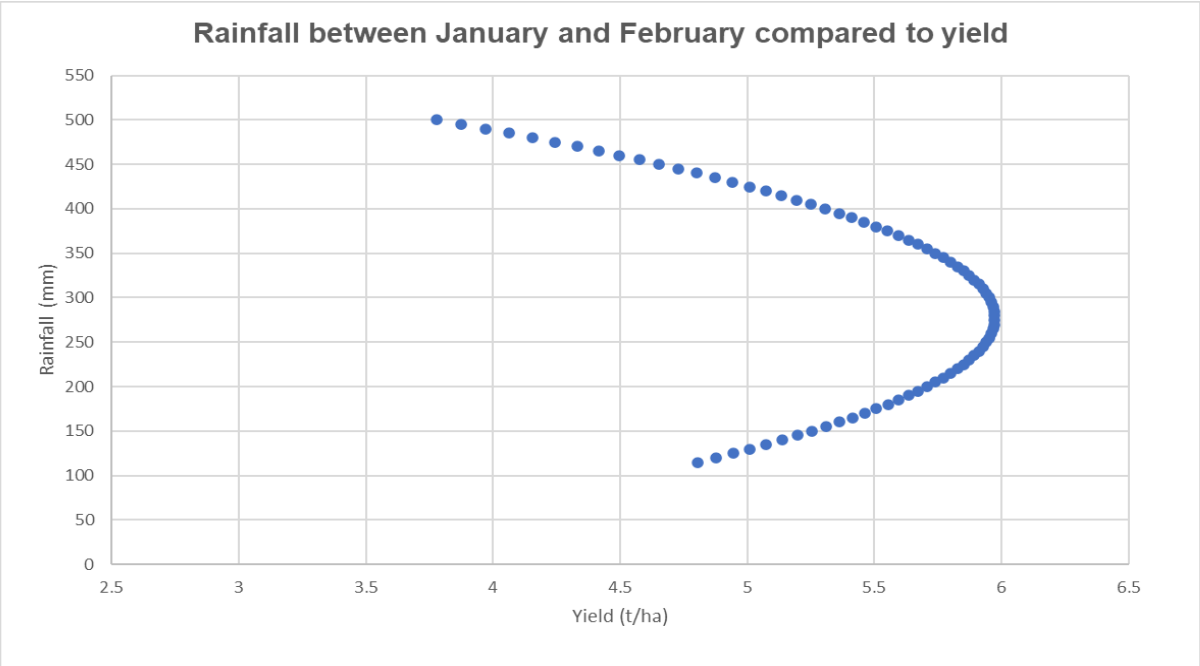

Figure 4.8: Yield and rainfall relationship in January and February
Source: Compiled by author

Figure 4.8 indicates that the optimal amount of rainfall that provides the highest yields is 275mm. As mentioned in section 4.2.7, the average rainfall in January and February is 175mm a year, this will be used as the initial (index) rainfall value (S_0) for the options. The strike rate (K) of the option will be the rainfall amount that the buyer wants to hedge against. Different scenarios will help to prove whether rainfall options are efficient.

In this study, it will also be assumed that when the option reaches intrinsic value and the option realises, the payout will be determined by the difference in yield according to the rainfall amount achieve. The scale for this will be the forecasting of rainfall, which is Table 4.7. The difference in yield will then be paid according to the advanced agreed spot price of maize. It was also clear that to be able to price rainfall options, rainfall needs to have a value. It was concluded that the average rainfall of 175mm in January and February will give you an average of 5.51t/ha of maize. Derived from the data, it was concluded that 1mm of rainfall will give you 0.03149t/ha of maize. To determine the premium cost, the value of the option price multiplied by the spot price and 0.03149t/ha will determine the cost of the premium needed to be paid.

In the scenarios, it is assumed that the producer price is R4000 p/t and the duration of the option is three months (option is bought during planting (December) and held until the end of February (most rain-yield sensitive period)), the interest rate is 7.37 per cent and the volatility of rainfall is 35 per cent.

4.2.8.1 Long Put option

When the buyer of the option wants to hedge against too little rainfall, he or she will buy a long put (most simplistic strategy). This protects the holder of the put option against too little rainfall during January and February, which can result in poorer yields. For all the put scenarios, it is assumed that it will only rain 120mm for January and February, 120mm of rainfall provides an average yield of 4.876182t/ha according to the yield forecasting table (see Table 4.7). The 120mm of rainfall is used to determine the payout a farmer can achieve; this is just a benchmark to explain the payout concept with the different scenarios to determine the difference in yield. In reality, the amount of actual rainfall, with the yield forecasting table (see Table 4.7), will be used to determine the payout.

Scenario 1 – At the money (ATM) put option

In this scenario, the option will be at the money. The index value (S_0) will be 175mm because it is the average amount of rainfall achieved during January and February, and the strike value (K_0) will also be 175mm because the put option is ATM. According to the Black-Scholes formula, the option price is 10.56. At a SAFEX spot price of R4000.00 p/ton, it will provide a premium cost of R1 330.06 p/ton. The premium cost is calculated by the spot price (R4000.00), multiplied by the option price (10.56), multiplied by 0.03149, which is the amount of yield achieved for every millimetre of rain achieved (see section 4.2.8).

If it only rains 120mm in January and February as assumed, the farmer will only harvest 4.876182t/ha according to Table 4.7. According to the assumptions, the difference in yield is

0.634237t/ha (5.510419 – 4.876182) and at R4000.00 p/ton, it will give the buyer a payout of R2 536.95 and a net profit of R1 206.89 (R2 536.95 – R1 330.06) if the option is exercised. In this scenario, the option will pay out for any amount of rainfall less than the strike amount of 175mm. Note that the option pays out the difference in yield for every millimetre of rain below 175mm in this scenario.

Scenario 2 – In the money (ITM) put option

In this scenario, the option will be in the money. The index value (S_0) will stay 175mm because it is the average rainfall for this period and the strike value (K_0) will be 275mm; a strike value of 275mm of rainfall was chosen because this is the optimal point of rainfall. According to the Black-Scholes formula, the option price is 95.06. At a SAFEX spot price of R4000.00 p/ton, it will provide a premium cost of R11 973.16 p/ton. The premium of this put is very expensive and will not be chosen as an effective hedging option. The premium cost is calculated by the spot price (R4000.00), multiplied by the option price (95.06), multiplied by 0.03149, which is the amount of yield achieved for every millimetre of rain achieved (see section 4.2.8).

According to the assumptions, the difference in yield stays the same (0.634237t/ha) because the rainfall amount is still only 120mm and at R4000.00 p/ton, it will give the buyer a payout of R2 536.95 but a loss of R9 436.21 (R11 973.16 – R2 536.95) if the option is exercised. Note that the option pays out the difference in yield for every millimetre of rain below 275mm in this scenario.

Scenario 3 – Out of the money (OTM) put option

In this scenario, the option will be in the money. The index value (S_0) will stay 175mm because this is the average rainfall for the period and the strike value (K_0) will be 135mm. The strike value of 135mm was chosen because as mentioned before, 135mm is the minimum amount of rainfall needed to achieve 39 per cent profit on input cost. No one wants less than 135mm of rain because it will hurt profit. According to the Black-Scholes formula, the option price is 0.64. At a SAFEX spot price of R4000.00 p/ton, it will provide a premium cost of 79.99 p/ton. The premium cost is calculated by the spot price (R4000.00), multiplied by the option price (79.99), multiplied by 0.03149, which is the amount of yield achieved for every millimetre of rain achieved (see section 4.2.8).

According to the assumptions that it will only rain 120mm for January and February, the difference in yield still stays the same (0.634237t/ha) because the rainfall amount is still only 120mm, and at R4000.00 p/ton, it will give the buyer a pay out of R2 536.95 but a profit of R2 456.96 (R2 536.95 – R79.99) if the option is exercised. This scenario is the most profitable hedging tool for farmers. Note that the option pays out the difference in yield for every millimetre of rain below 135mm in this scenario.

4.2.8.2 Long Call options

When the buyer of the option wants to hedge against too much rainfall, he or she needs to purchase a call option (long call option). The long call option provides protection against too much rain, which has a negative impact on maize yields. For all the call scenarios, it is assumed that it will rain 290mm for January and February, providing an average yield of 5.966562t/ha according to the yield forecasting table (see Table 4.7). The 290mm of rainfall is used to determine the payout a farmer can achieve; this is just a benchmark to explain the payout concept with the different scenarios to determine the difference in yield. The amount of actual rainfall, with the yield forecasting table (see Table 4.7) will be used to determine the payout.

<u>Scenario 1 – At the money (ATM) call options</u>

In this scenario, the option will be at the money. The index value (S_0) will be 175mm because it is the average amount of rainfall achieved during January and February and the strike value (K_0) will also be 175mm because the call option is ATM. According to the Black-Scholes formula, the option price is 13.75. At a SAFEX spot price of R4000.00 p/ton, it will provide a premium cost of R1 732.46 p/ton. The premium cost is calculated by the spot price (R4000.00), multiplied by the option price (13.75), multiplied by 0.03149, which is the amount of yield achieved for every millimetre of rain achieved (see section 4.2.8).

According to the assumptions it will rain 290mm for January and February, given a yield of 5.966562t/ha. If it rains 290mm, the difference in yield is 0.456143t/ha (5.966562 - 5.510419); it is the difference between the average yield received at the average rainfall and the yield received when getting 290mm of rainfall. At a rainfall amount of 490mm and at a spot price of R4000.00 p/ton, it will give the buyer a pay out of R1 824.57 and a profit of R92.11 (R1 824.57 – R1 732.46) if the option is exercised. Note that the option pays out the difference in yield for every millimetre of rain above 175mm in this scenario.

<u>Scenario 2 – Out of the money (OTM) call option</u>

In this scenario, the option will be out of the money. The index value (S_0) will stay 175mm because it is the average rainfall amount achieved during January and February, and the strike value (K_0) will be 275mm for the option to be OTM. This is the optimal point of rainfall to achieve the highest yields, higher rainfall than 275mm will decrease yields. According to the Black-Scholes formula, the option price is 0.08. At a SAFEX spot price of R4000.00 p/ton, it will provide a premium cost of R10.26 p/t. The premium cost is calculated by the spot price

(R4000.00), multiplied by the premium cost (10.26), multiplied by 0.03149, which is the amount of yield achieved for every millimetre of rain achieved (see section 4.2.8).

According to the assumptions, the difference in yield is still 0.456143t/ha because it is assumed that it will rain 290mm. At R4000.00 p/ton spot price, the buyer will receive a pay out of R1 824.57 and a profit of R1 814.31p/t (R1 824.57 – R10.26) if the option is exercised. Note that the option pays out the difference in yield for every millimetre of rain above 275mm in this scenario.

Scenario 3 – Out of the money (OTM) call option

In this scenario, the option will be out of the money. The index value (S_0) will stay at 175mm because it is the average rainfall amount achieved during January and February and the strike value (K_0) will be 420mm. If it rains more than 420mm during January and February, the maize won't provide a yield that is profitable at 39 per cent on input cost. According to the Black-Scholes formula, the option price is 0.00. At a SAFEX spot price of R4000.00 p/ton, it will provide a premium cost of R0 p/ton. This is because the option is too far out of the money, meaning the strike rate is bigger than the index value.

According to the assumptions, the difference in yield is still 0.456143t/ha because it is assumed that it will rain 290mm and at R4000.00 p/ton spot price it will give the buyer a pay out of R1 824.57 and a profit that will be the same as the payout of R1 824.57 if the option exercises. The reason is that the option is so far out of the money the premium cost is R0; the profit is the same as the payout amount.

In these different scenarios, it is important to note that the cost of premiums will only change if the strike rate, time to maturity and volatility changes and is undependable on the SAFEX price. The pay-out price will only change if the SAFEX price changes, higher producer prices mean higher payouts.

4.2.9 Rainfall options compared to agriculture insurance

South African companies, like Santam, offer agricultural insurance products to cover risks that include drought, except on crops cultivated under irrigation, damage caused by uncontrollable insect pests, hail, wind and frost. In other words, with this type of cover, the farmer is covered against the uncontrollable elements of nature.

When looking at the differences between rainfall options and insurance, it is two different products, but both can be used to hedge against yield risk. The disadvantage of crop insurance is that there are currently no insurance products available in South Africa which provides protection against rainfall for maize; but only certain crops, such as wheat and grapes, are covered against yield loss and grade loss because of excessive rain during the physiological mature stage of these crops. Comparisons will be made on hail crop insurance in this study as it is provided as an insurance product for maize in South Africa.

It is important to note that rainfall options don't need a proper loss adjustment to determine the damages to pay out: instead, the option pays out based on the occurrence of nature. Rainfall options offer the opportunity of hedging against weather unpredictability by limiting the downside of traditional insurance by linking payoffs to measured weather indices

If a similar scenario is created as mentioned in section 4.2.8 for the options with insurance and there is assumed that the amount insured is R22 000 (5.5t/ha average yield of maize at R4000.00 SAFEX price), the premium will cost R264.00. This is 1.2 per cent of the amount that is insured, and the going rate in the North-Western Free State is 1 to 1.2 per cent of the amount that is being insured (Santam, 2016). Compared to the OTM put option with a strike of 135mm, the insurance premium is more expensive than the premium option of R79.99. Same with the OTM call option, where the strike value is 275mm, the premium is R10.26.

It is important to note that insurance is for the whole harvest while the rainfall options are only for the difference in yield that will be lost due to too much or too little rainfall. That is also the reason for the big difference in payout because insurance hedges the whole harvest; whereas options only cover the difference in yield that will be lost due to the unpredictability of rainfall. It is also important to note that with insurance, you are not sure of the percentage of loss that will be paid out. Visible crop losses suffered are as a result of the direct impact of the hail, destroying parts of the plant, or the plant as a whole. This includes seeds/kernels thrashed out, plants of which the growing points are knocked off, leaves that are shredded, destroyed or knocked off, blades, stalks or stems that are knocked off or snapped, etc.

Damage after a hailstorm, that is not visible and therefore also not objectively quantifiable, such as delayed growth due to cold from hailstones collecting around a plant, is not covered. Damage, such as disease resulting from hail damage, is not covered. Many insurance companies have a policy that they don't pay out the first 10 to 15 per cent of the damage, this number depends on the company policy (Santam, 2016).

The uncertainty of payout is a disadvantage compared to rainfall options where payout is certain when the option is exercised. Another disadvantage of insurance is that the higher the producer price, the higher the premium of insurance, whereas options for rainfall don't depend on the producer price to determine their premium price.

4.3 Conclusion

The main purpose of this study was to see if weather derivatives can be used as a risk management tool for maize farmers in South Africa. According to the above-mentioned, rainfall options can be financially feasible to serve as risk management for yield risk for maize farmers.

Rainfall options cover low-risk, high-probability occurrences, whereas weather insurance, in general, covers high-risk, low-probability occurrences, as defined in a fully personalized policy.

Rainfall options offer the opportunity for farmers to ensure profitable yields even though the regular occurrences of rainfall with its unpredictability make it hard to hedge. Rainfall options offer the chance to hedge against something out of the farmer's control. The cost of the premium was calculated using the spot price per ton multiplied by the cost of the option, multiplied by 0.03149, which is the amount of yield achieved for every millimetre of rain achieved (see section 4.2.8). The OTM put option with a strike of 135mm has a premium option price of R79.99. Same with the OTM call option, where the strike value of 275mm has a premium option price of R10.26. Compared to hail insurance where the cost of insurance is 1 – 1.2% of the amount insured, dependable on the area, the cost of the premium was R264.00 (5.5t/ha average yield of maize at R4000.00 SAFEX price).

It is worth mentioning that insurance covers the entire harvest, whereas rainfall options only cover the difference in yield lost due to excessive or insufficient rainfall. That is also the reason for the large difference in payout, because insurance hedges the entire harvest while options only hedge the portion of the harvest that will be lost due to the unpredictability of rainfall, resulting in a difference in yield achieved. The profit on payout with insurance is higher than rainfall options but has more disadvantages like loss adjustment, while rainfall options pay out when the index is triggered.

With rising input costs and the unpredictability of weather occurrences that keep rising each year, rainfall options can be seen as a cheaper alternative to hedge against yield risk. With cheaper premiums than insurance, it offers farmers the chance to hedge their harvest and to still be able to achieve a 39 per cent profit on input cost.

Basis risk is discussed in section 2.6.4 because of the strong impact it has on the success of hedging rainfall options. The efficiency of hedging is significantly diminished when the location of agricultural production is only a short distance from the closest reference weather station. The efficiency of hedging is further reduced if an additional index that has a weak association to yield also underlies the option.

Access to data, both in terms of regulatory requirements and purchase cost, may pose problems. As a result, the greater the ease of access and the lower the cost of weather data, the greater the opportunities for developing weather derivatives.

For this study to be implemented in practice it is important to focus on independent weather data at specific locations. This will mean more weather stations on farms for data to be more accessible. Improved data availability will make the product more attainable and attractive.

Chapter 5

Conclusion and Recommendations

5.1 Summary

This study is associated with the complexity that farmers face with the yield risk of maize. Weather uncertainty increased the risk. The only tool farmers have at hand to protect themselves against yield risk is MPCI. However, MPCI serves in general, high-risk, low-probability occurrences. Although crop insurance is available in South Africa, the uptake is low due to the expensive costs.

Weather derivatives differ from crop insurance because it covers low-risk, high-probability occurrences like rain. This paper will focus on rainfall options as a hedging alternative for farmers to mitigate yield.

The primary objective of this study was to identify if weather derivatives can be used as a risk management tool for farmers in South Africa to manage yield risk.

5.2 Literature Review and results of the study

The study started with a broad overview of the maize market in South Africa, as well as the more practical side like harvesting, planting and uses of maize, and the minimum government support South African farmers receive. It also focuses on the risks of farming, which is highly dependent on changing weather. Chapter 1 also explained the importance of climate change and how dependent the South African economy is on agriculture. It also focused on the importance of hedging against variables to make sure farmers stay financially sustainable due to the rising input costs and lower profits. This was followed by an introduction of the research objectives (theoretical and empirical) as well as the research design and methodology. Ethical considerations were also outlined.

The main objective in Chapter 2 was to look at different factors that affect maize yield and production in South Africa. In-depth literature studies from Du Plessis (2003), Moeletsi (2017), Landman *et al.* (2017), and Mbotho (2018) were evaluated to identify the different characteristics of the maize market in South Africa and the effect of climate change on producers' decisions to mitigate risk. These studies also evaluate the sensitivity of maize yields concerning optimal rainfall during critical stages of the maize plant. Studies from Berlage (2013), Kornher and Kalkhuhl (2013), and Nhamo *et al.* (2019) assess the impact of climate change on production in Southern Africa.

The chapter focuses on the low-profit margins achieved by maize farmers during periods of adverse rainfall. Thereafter, different insurance products available to farmers to mitigate yield risk were discussed. The chapter also explained the weather derivatives and their application in South Africa. This chapter included the reviews of previous similar studies done on weather derivatives, like Geyser and Van der Venter (2001), Spaulding *et al.* (2003), Geyser (2004), Vedenov and Barnett (2004), Torriani *et al.* (2008*),* Zara (2010), and Wang *et al.* (2013).

Geyser and Van der Venter (2001) studied the feasibility of weather derivatives in the South African agricultural market. They conclude that weather derivatives will be beneficial for farmers and will only be successful if their introduction goes along with the educational process. Spaulding *et al*. (2003) examined the effect of rain put options on maize and wheat production in Romania. According to the findings, the weather derivatives application can reduce output variation by 39%. Geyser (2004) examined the application of weather derivatives in South Africa using the benefits of rainfall options as a yield risk management tool and suggested an options strategy for agriculture. The study concluded that the availability of adequate weather statistics does not appear to be a barrier to the development of weather derivatives in agriculture. Access to the data, both in terms of bureaucratic procedures and purchase cost presents challenges. Vedenov and Barnett (2004) investigated the effectiveness of weather derivatives in corn, soybean, and cotton production in the United States. The results show that the weather derivatives application reduces output semi-variance by 16.6 to 77.1 per cent. Call options were based on the temperature index, while put options were based on a rainfall index. The results show that using weather derivatives reduces semi-variance regardless of the underlying index. However, in terms of mitigating weather risk in corn production, temperature options outperform rain options. Torriani *et al.* (2008) investigated the efficacy of rain put options in Swiss maize production. The authors use value-at-risk (VaR) as a risk measure, and the results show that using weather derivatives reduces the maximum possible loss due to adverse weather. Based on the literature reviewed, it can be concluded that weather derivatives' results vary according to crop, geographical location and period. Zara (2010) investigated the efficacy of weather derivatives in the production of wine grapes in France. The results show that the use of a strangle option strategy reduces the volatility of the economic value of grape production by 22.06 per cent when compared to the economic value of grape production without the use of weather derivatives. Locally, Wang *et al*. (2013) studied farmers' demand for weather index-based crop insurance and concluded that insured growers can benefit more from multivariate weather indices.

Chapter 3 explained the research design and methodology adopted in this study. This research topic and the secondary use of data automatically led the researcher to use a quantitative design. An explanation of the secondary data, the period, data evaluation and the data resources were provided together with the process.

Chapter 4 addressed the empirical objectives, which were to explain the maize yield-at-risk relationship with rainfall. In this section, it was confirmed that the growing period of maize from January to February has the highest correlation with yield (0.64785). This indicated that this period is the most crucial for good rainfall to receive good yields. It also determined the average rainfall index for the growing period of white maize in the North-Western Free State. The average rainfall in this area is 528mm of rain per annum.

Additionally, research on the interaction between crops and climate around the world has shown that weather and climate have a significant impact on agricultural yields. In Nigeria, inter-annual rainfall variability is a major cause of stress to farming and crop production (Adejuwon, 2005). In Argentina, Podesta *et al*. (1999) demonstrated that climate variability is strongly correlated with yields of maize, sorghum, and soybeans in the Pambas, Southern Argentina, as a result of El Nino Southern Oscillation.

Chapter 4 also determined profit margins with historical input costs of white maize. It was concluded that the water table soil area in the North-Western Free State can offer 39 per cent profit on input cost. Using the historical data, it was seen that a farmer in the area needs to harvest 5.38t/ha to make a profit of 39 per cent on input cost. VaR was used to determine the confidence level; a farmer can still achieve a 39 per cent profit margin on input costs with the worst yields. It was seen that 99 per cent confidence level chances are with a -5.53 per cent deviation; the minimum that a farmer can harvest is 5.08t/ha to still be able to receive 39 per cent profit on input costs. It is critical to not have a greater deviation than 5.53 per cent of the average profit on input cost, which is 39 per cent on average. After that was determined, the amount of rainfall that was needed during January and February to receive 5.08t/ha and the amount that will start to affect this ton per hectare negatively was determined.

A study by Blanc *et al.* (2016) using both production and profit functions examined the factors that affect family farms' productivity in Senegal. A survey of 504 agricultural families yielded the inputs and outputs data used in the econometric study. The key findings showed that crop yields are negatively impacted by the size of the cultivated plots, a phenomenon known as diseconomies of scale. The research implies that agricultural management and organization may be improved. Additionally, the growth of commercialization industries and loans may increase agricultural inputs. The findings indicate that yields and prices play major and crucial roles for all crops in terms of profitability. To raise unit pricing, and therefore, their profits, farmers would need to have greater bargaining power.

After the specific yield of 5.08t/ha was confirmed to achieve a 39 per cent profit on input costs, the next step was to calculate the amount of rainfall needed in January and February to achieve 5.08t/ha. It was seen that the average rainfall during this period is 175mm, which will give you an average of 5.51t/ha yield. The results also presented that 135mm in January and February is the minimum amount of rainfall one can achieve to still be able to make 39 per cent profit on input cost. 135mm in this period will give you a yield of 5.075t/ha. The results also showed the maximum amount of rainfall that a farmer can achieve during January and February is 420mm, as the crop would still be profitable at 39 per cent on input cost at this level of rainfall. It was also clear that the optimum amount of rainfall is 275mm during January and February, 275mm of rainfall will give you the highest yield, which is also the turning point. Yield will increase with higher levels of rainfall until 275mm, after 275mm yields will start to decrease.

According to Chen *et a*l. (2017), except for the emergence phase, rainfall deficiencies throughout the major maize growth phases satisfactorily account for yield losses. The success of the indices with minimal basis risk is highlighted by correlation coefficients between payouts of the cumulative rainfall deficit indices and yield reductions that range from 0.86 to 0.96. SA-Xintai (correlation 0.71) is an exception, where a total rainfall deficit index performs better (0.87). Risk premium rates, which accurately reflect the risk of drought, range from 5.6 per cent to 12.2 per cent.

Chapter 4 also included the price of rainfall options through the Black Scholes Model. It was assumed that the options will be taken out at the start of the planting season, which would be December. The time to maturity was then three months, expire the end of February. It was clear that a farmer needs to hedge against rainfall lower than 135mm and higher than 275mm. The options premiums at these levels were cheap, at R79.99 and R10.26, respectively, which is clearly profitable at these levels in the certain scenario. It was assumed that for the put option it will only rain 120mm and at R4000.00 p/ton spot price it will give the buyer pay out of R2 536.95 but a profit of R2 456.96 (R2 536.95 – R79.99) if the option is exercised. For the call option, it was assumed that it will rain too much, 290mm, which affects yields negatively; at R4000.00 p/ton spot price, it will give the buyer a pay out of R1 824.57 and a profit of R1 814.31p/t (R1 824.57 – R10.26) if the option is exercised. The premiums of rainfall options are also cheaper than regular insurance in the same scenario, which was R264. In this chapter, it was highlighted that rainfall options only offer to hedge the amount of yield difference that will be missed due to too much or too little rainfall but will pay out when nature occurs. On the other, it was noted that regular crop insurance ensures the whole harvest, but it must be noted that payout only occurs after the loss adjustment has been assessed.

5.3 Limitations and recommendations for further studies

The data in this research only followed a time frame of twenty years. It is recommended that future studies use a longer data period that extends beyond the 2020/2021 season to counter the potential impact of specific events like the Ukraine and Russia conflict and the impact these circumstances had on the general economy and the maize market, and maize futures prices.

It is also recommended that further studies consider a solution for basis risk. According to Mushoff *et al.* (2011), basis risk has a very strong impact on the success of hedging rainfall options. The efficiency of hedging is significantly diminished when the location of agricultural production is only a short distance from the closest reference weather station. The efficiency of hedging is further reduced if an additional index that has a weak association to yield also underlies the option, which was seen between the wheat yield and the rainfall sum index in their study.

Access to data, both in terms of regulatory requirements and purchase cost, may pose problems. As a result, the greater the ease of access and the lower the cost of weather data, the greater the opportunities for developing weather derivatives. For this study to be implemented in practice it is important to focus on independent weather data at specific locations. This will mean more weather stations on farms for data to be more accessible. Improved data availability will make the product more attainable and attractive. As with any other weather derivative, developing weather derivatives for agriculture requires that the weather variable be quantifiable, that historical records be sufficient and readily accessible, and that all parties to the transaction view such measures as objective and dependable.

More limitations were that rainfall and yield were district wide. Although the average damage across the area is calculated correctly, it is not distributed correctly among the payers. Considering how variable the geographical distribution of rainfall is, the rainfall measured at a specific point is only valid for the area of the rain gauge and can vary within meters and even kilometres.

Total rainfall was used and the amount and timing of rainfall which has a greater influence on yield was ignored. Another issue is that if rainfall is used as an indirect indicator of yield, how long should it be measured and compared to a predetermined number of millimetres. For example, a two-month period of rainfall is "guaranteed" from January 1 to February 28, this does not specify when the rain will fall. If most of the rain falls in the first week of January one year and the same amount falls in the last week of February the next, the insurance coverage remains the same; but in practice, it could mean the difference between a record harvest or no harvest. Because rainfall is so variable, the premium or tariff will be so high that no one will be able to afford it from a tariff calculation standpoint; future calculations could focus on developing a 10-day rainfall index.

Temperature is ignored in this study; it was assumed that temperature is indirectly reflected in rainfall data since periods of low rainfall are normally associated with periods of higher temperature; future studies can include temperature to see the real effects on yield.

5.4 Conclusion

This study looks at the feasibility of weather derivatives in the context of South African agriculture and offers a suitable approach for employing options on rainfall as a yield risk management tool. A weather derivative can be used as a hedging instrument by farmers and risk insurers when a weather phenomenon is a source of economic risk for agriculture.

Farmers in South Africa may gain greatly from the adoption of weather derivatives to control yield risks in agricultural markets. Farmers could be able to concentrate more on the actual farming process if they combine, for instance, a rainfall option strategy with current insurance policies and agricultural futures contracts because the main risk categories – yield, event, and price risks – would all have been hedged.

This study confirmed that rainfall options can be financially feasible in South Africa, especially in the water table soil region in the North-Western Free State. Although it was seen that you won't grow financially forward in the farming business, it was seen that it is a way to limit the downside and still offer 39 per cent profit on input cost like the area offer. It was also clear that it can be seen as a risk management tool to hedge against yield risk. In an agricultural variable world with a lot of variables out of the producer's control, this can be seen as a way to manage one of the many uncontrollable variables.

Reference list

Adejuwon, J.O. 2005. Food crop production in Nigeria. I. Present effects of climate variability. *Climate Research*, 30(1):53-60.

Aker, J.C. 2010. Information from markets near and far: Mobile phones and agricultural markets in Niger. *American Economic Journal: Applied Economics*, 2(3):46–16.

Alzarrad, M.A., Moynihan, G.P. and Vereen, S.C. 2017. Weather derivatives as a risk management tool for construction projects. *In Proceedings of the 6th CSCE/CRC International Construction Specialty Conference, June 2017*:1-9.

Araujo, C., Bonjean, C.A., Combes, J.L. & Motel, P.C. 2005. Devaluation and cattle market integration in Burkina Faso. *Journal of African Economies*, 14(3):359–384.

Ariyanti, D., Riaman, R. & Irianingsih, I., 2020. Application of Historical Burn Analysis Method in Determining Agricultural Premium Based on Climate Index Using Black Scholes Method. *JTAM (Jurnal Teori dan Aplikasi Matematika)*, *4*(1):28-38.

Asteriou, D. & Hall, S.G. 2011. Applied Econometrics: a modern approach. England: Palgrave MacMillan.

Aydinalp, C. & Cresser, M.S., 2008. The effects of global climate change on agriculture. *American-Eurasian Journal of Agricultural & Environmental Sciences*, *3*(5):672-676.

Bafana, B. 2017. The High Price of Desertification: 23 Hectares of Land a Minute. *Inter Press Service.* http://www.ipsnews.net/2017/06/the-high-price-of-desertification-23-hectares-of-land-a-minute/?utm_source=rss&utm_medium=rss&utm_campaign=the-high-price-of-desertification-23-hectares-of-land-a-minute Date of access: 28 January 2023.

Bang, 2019. Long Straddle. *Investopedia*. https://www.investopedia.com/terms/l/longstraddl Date of access: 28 April 2022.

Banse, M., Jansson, T., Eickhout, B., Sulser, T. & Ringler, C. 2008. Analysis of major challenges and constraints – trade and market measures and policies. *AG2020 Project – Foresight Analysis for World Agricultural Markets (2020) and Europe*, January 2007 to December 2009, Contract No. 44280-AG2020.

Barnett, B. & Mahul, O. 2007. Weather index insurance for agriculture and rural areas in lower-income countries. *American Journal of Agricultural Economics*, 89:1241–1247.

Barnett, B., Barrett, C. & Skees, J. 2008. Poverty traps and index-based risk transfer products. *World Development,* 36:1766–1785.

Benhin, J.K., 2006. *Climate change and South African agriculture: Impacts and adaptation options*, 21. CEEPA discussion paper.

Berlage, K. 2013. The weather business: How companies can protect against increasing weather volatility. *Allianz Global Corporate and Specialty Reports*.

Blaker, T.N., 2021. *Farm-level barriers to the adoption of precision agriculture technologies in the South African maize industry: variable rate application, section control, and guidance* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Blanc, E., Lepine, A. & Strobl, E. 2016. Determinants of crop yield and profit of family farms: evidence from the Senegal River Valley', Experimental Agriculture, 52(1):110–136.

Blignaut, J. Ueckermann, L. & Aronson, J. 2009. Agriculture production's sensitivity to changes in climate in South Africa. *South Afr. J. Sci*., 105:61–68.

Botai, C.M., Botai, J.O. & Adeola, A. M. 2018. Spatial distribution of temporal precipitation contrasts in South Africa, *South African Journal of Science*, 114(7/8):70–78

Botoş, H.M. & Ciumaş, C., 2012. The use of the Black-Scholes model in the field of weather derivatives. *Procedia Economics and finance*, 3:611-616.

British Broadcasting Centre (BBC), 2021. Briefs no. 41. Ithaca, NY: International service for the acquisition of Agribiotech. What is climate change? A really simple guide. *BBC News, Science*. https://www.bbc.com/news/science-environment-24021772 Date of access: 23 May 2022.

Brockett, P.L., Wang, M. & Yang, C. 2005. Weather derivatives and weather risk management. *Risk Management and Insurance Review*, 8(1):127–140.

Buckley, N., Hamilton, A., Harding, J., Roche, N., Ross, N., Sands, E., Skelding, R., Watford, N. & Whitlow, H. 2002. European weather derivatives. *In General Insurance Convention*. Working Paper.

Bureau for Food and Agricultural Policy (BFAP), 2021. *Perspective on agriculture's performance in quarter 4 of 2020.* https://www.bfap.co.za/wp-content/uploads/2021/03/202110-Mar_Ag-GDP-Publication_Final.pdf Date of access: 26 May 2022.

Bureau for Food and Agricultural Policy (BFAP), 2022. BFAP baseline agricultural outlook 2022 - 2030. https://www.sagis.org.za/BFAP-BASELINE-2022.pdf Date of access: 25 January 2023.

Camberlin, P. & Okoola, R.E. 2003. The onset and cessation of the 'Long Rains' in eastern Africa and their interannual variability. *Theoretical Application Climatol*. 75:43–54.

Campbell, R. 2020. South African agriculture is dependent on imports for key inputs. *Engineering News*, 1st May 2020. https://www.engineeringnews.co.za/article/south-african-agriculture-is-dependent-on-imports-for-key-inputs-2020-05-01 Date of access: 14 March 2022.

Canadian Derivatives Institute (CDI). 2021. Hedging against climate risks using weather derivatives. *Investment Executive*. https://www.investmentexecutive.com/inside-track_/the-canadian-derivatives-institute/hedging-against-climate-risks-using-weather-derivatives/ Date of access: 26 May 2022.

Chen, W., Hohl, R. & Tiong, L.K. 2017. Rainfall index insurance for corn farmers in Shandong based on high-resolution weather and yield data, *Agricultural Finance Review*, 77(2):337-354.

Corporate Finance Institute (CFI), 2022. What is Value at Risk (VaR)? https://corporatefinanceinstitute.com/resources/knowledge/trading-investing/value-at-risk-var/ Date of access: 2 June 2022.

Cousins, B. & Walker, C. 2015. *Land Divided, Land Restored: Land Reform in South Africa for the 21st Century*. Cape Town: Jacana Publishers.

Crop Estimates Committee (CEC), 2020. Maize production overview - 2019/20 season. *South African Maize Crop Quality Report 2019/2020 Season. https://sagl.co.za/wp-content/uploads/Maize-Crop-Quality-Report-2019-2020.pdf* Date of access*:* 16 March 2022.

Crop Estimates Committee (CEC), 2021. Maize production overview - 2019/20 season. *South African Maize Crop Quality Report 2020/2021 Season. https://sagl.co.za/wp-content/uploads/Maize-Crop-Quality-Report-2020-2021.pdf* Date of access*:* 28 February 2023.Dalhaus, T., Musshoff, O. & Finger, R. 2018. Phenology information contributes to reduce temporal basis risk in agricultural weather index insurance. *Scientific reports*, 8(1):1–10.

Dell, M., Jones, B.F. & Olken, B.A. 2008. Climate change and economic growth: Evidence from the last half century. *National Bureau of Economic Research Working Paper Series*, No. 14132 http://www.nber.org/papers/w14132 Date of access: 23 May 2022.

Dischel, R.S. & Barrieu, P. 2002. Financial weather contracts and their application in risk management. *Climate Risk and the Weather Market: Financial Risk Management with Weather Hedges.* Risk Books, London, UK, 25–42.

Drury, L. 2019. The surprising history of maize. *Bright Maize* https://www.brightmaize.com/surprsing-history-maize/ Date of access: 24 May 2022.

Du Toit, A.S., Prinsloo, M.A., Durand, W. & Kiker, G. 2002. Vulnerability of maize production to climate change and adaptation in South Africa. *Combined Congress: South African Society of Crop Protection & South African Society of Horticultural Science.* Pietermaritzburg, South Africa.

Elum, Z.A., Nhamo, G. & Antwi, M.A. 2018. Effects of climate variability and insurance adoption on crop production in select provinces of South Africa. *Journal of Water and Climate Change*, *9*(3):500-511.

Engel, K. 2021. The agriculture sector in SA is booming with employment opportunities. *Independent Online,* 27 December 2021. https://www.iol.co.za/capeargus/news/the-agriculture-sector-in-sa-is-booming-with-employment-opportunities-5d81077c-76b7-43ed-acef-16edab1eda29 Date of access: 18 May 2022.

Food and Agriculture Organization (FAO), 2012. Agriculture Department, Agricultural Production, Livestock Primary. Total World Meat 1970–2010, Food Balance Sheets, Japan, USA; FAO: Rome, Italy.

Food and Agriculture Organization (FAO), 2021. FAO leads training sessions as part of a new course on 'Agricultural meteorology for CSA'. *Climate-Smart Agriculture.* https://www.fao.org/climate-smart-agriculture/news/detail/en/c/1393520/ Date of access: 23 May 2022.

Food and Agriculture Organization of the United Nations (FAO). 2020. *Crop Yields*. https://ourworldindata.org/crop-yields Date of access: 14 March 2022.

Geman, H. 2015. Agricultural Finance: From Crops to Land, Water and Infrastructure. John Wiley & Sons, Incorporated, New York, 1:187-188.

Geyser, J. 2004. Weather derivatives: concept and application for their use in South Africa. *Agrekon*, 43(4):444–464.

Geyser, J.M. & Van de Venter, T.W.G. 2001. *Hedging maize yield with weather derivatives*. https://ageconsearch.umn.edu/record/18067 Date of access: 22 February 2022.

Giaoutzi, M., Stratigea, A., Van Leeuwen, E. & Nijkamp, P. 2012. Scenario analysis as a foresight tool in agriculture. *International Journal of Foresight and Innovation Policy*, 8(2–3): 105–128.

Gloy, B.A. & T.G. Baker 2001. A Comparison of Criteria for Evaluating Risk Management Strategies. *Agricultural Finance Review*, 61: 36-56.

Gouse, M., Sengupta, D., Zambrano, P. & Zepeda, J.F. 2016. Genetically modified maize: less drudgery for her, more maize for him? Evidence from smallholder maize farmers in South Africa. *World Development*, *83*: 27-38.

Grain SA, 2018. KEY FACTORS that influence local maize prices. *Agricultural Economist: Grain SA.* https://www.grainsa.co.za/key-factors-that-influence-local-maize-prices Date of access: 24 May 2022.

Grain SA, 2020. *Summer Crop Scenario Report*. https://www.grainsa.co.za/upload/report_files/BFAP-Summer-Crop-Scenario-Report-November-2020.pdf Date of access: 22 February 2022

Grain SA, 2022. North-West Free State budget (2021/22 production season). *Report Documents*. https://www.grainsa.co.za/report-documents?cat=10 Date of access: 5 May 2022.

Greyling, J.C. & Pardey, P.G. 2019. Measuring Maize in South Africa: the shifting structure of production during the Twentieth Century, 1904–2015. *Agrekon*, 58(1):21–41.

Hawkins, N. 2020. *The Maize Forum*. https://www.sagis.org.za/Forum_Maize_20201120.pdf Date of access: 16 March 2022.

Huirne, R.B.M. 2003. Strategy and risk in farming. *NJAS: Wageningen Journal of Life Sciences*, 50(2):249-259.

Ikisan, 2022. Maize water management. *AgriInformation & Services*. https://www.ikisan.com/tg-maize-water-management.html Date of access 2 June 2022.

Insurance Information Institute (III), 2022. *Understanding crop insurance.* https://www.iii.org/article/understanding-crop-insurance Date of access: 3 May 2022.

Inter - American Development Bank (IDB), 2020. Factsheet Resilience Solutions for the Maize Sector in South Africa. https://publications.iadb.org/publications/english/document/Factsheet-Resilience-Solutions-for-the-Maize-Sector-in-South-Africa.pdf Date of access: 4 May 2022.

International Trade Administration (ITA), 2021. South Africa - Agricultural Sector. *Country Commercial Guides*. https://www.trade.gov/country-commercial-guides/south-africa-agricultural-sector Date of access: 26 May 2022.

Ivana, S., Kristina, P. & Tomislav, B. 2016. Effectiveness of weather derivatives as a hedge against the weather risk in agriculture. *Agricultural Economics*, 62(8):356–362.

James, C. 2009. Global status of commercialized biotech/GM crops. *ISAAA*

Jewson, S. & Brix A. 2005. *Weather Derivative Valuation: The Meteorological, Statistical, Financial and Mathematical Foundations*. Cambridge University Press, Cambridge.

Jones, B.F. & Olken, B.A. 2010. Climate shocks and exports. *National Bureau of Economic Research.* http://www.nber.org/papers/w15711 Date of access: 23 May 2022.

Jones, T.L. 2007. Agricultural applications of weather derivatives. *International Business & Economics Research Journal (IBER)*, 6(6).

Kornher, L. & Kalkuhl, M. 2013. Food price volatility in developing countries and its determinants. *Quarterly Journal of International Agriculture*, 52(4): 277–308.

Kotze, I & Rose, M. 2015. *Farming Facts and Futures: Reconnecting South Africa's food systems to its ecosystems*. WWF-SA, Cape Town, South Africa.

Kriel, G. 2021. Bringing transparency to crop insurance. *Farmer's Weekly*. https://www.farmersweekly.co.za/agri-business/agribusinesses/bringing-transparency-to-crop-insurance/ Date of access: 3 May 2022.

Kumar, R. 2014. Research methodology: a step-by-step guide for beginners. 4th ed. California: SAGE Publications.

Landman, W.A. Engelbrecht, F. Hewitson, B. Malherbe, J. & Van Der Merwe, J. 2017. Towards bridging the gap between climate change projections and maize producers in South Africa. *Theor. Appl. Clim*., 132:1153–1163.

Le Roux, N. 2009. *Seasonal maize yield simulations for South Africa using a multi-model ensemble system* (Doctoral dissertation, University of Pretoria).

Leblois, A. & Quirion, P. 2013. Agricultural insurance based on meteorological indices: realizations, methods and research challenges. *Meteorological Applications*, 20:1–9.

Leggio K.B. 2007. Using weather derivatives to hedge precipitation exposure. *Managerial Finance*, 33: 246–252.

Leobacher, G. & Ngare, P. 2011. On modelling and pricing rainfall derivatives with seasonality. *Appl. Math. Finance*, 18(1):71–91.

Louw, C. 2018. Long and short of the diesel rebate. *Grain SA*, 2018.

Mahul, O. & Stutley, C. 2008. Government Support to Agricultural Insurance: Challenges and Options for Developing Countries. *Annex E International Experiences with Agricultural Insurance: Findings from a World Bank Survey of 65 Countries*. http://documents.worldbank.org/curated/en/286991468332486571/Government-support-to-agricultural-insurance-challenging-and-options-for-developing-countries-annex-E Date of access: 24 May 2022.

Manfredo, M.R. & Leuthold, R.M. 1999. Value-at-Risk Analysis: A Review and the Potential for Agricultural Applications. *Review of Agricultural Economics,* 21: 99-111.

Manfredo, M.R. & Leuthold, R.M. 2001. Market Risk and the Cattle Feeding Margin: An Application of Value-at-Risk. *Agribusiness*, 17: 333-353.

Martin, S.W., Barnett, B.J. & Coble, K.H. 2001. Developing and pricing precipitation insurance. *Journal of Agricultural and Resource Economics*, 26:261–274.

Masipa, T. 2017. The impact of climate change on food security in South Africa: Current realities and challenges ahead. *Journal of Disaster Risk Studies*, 9(1):1–7.

Maja, M.M. and Ayano, S.F. 2021. The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries. Earth Systems and Environment, 5(2):271-283.

Moeletsi, E. 2010. Agroclimatological risk assessment of rainfed maize production for the Free State Province of South Africa. *Agrometeorology*, University of the Free State. (Thesis, Ph.D.).

Moeletsi, M.E. 2017. Mapping of maize growing period over the Free State Province of South Africa: heat units approach. *Advances in Meteorology, 2017*.

Moore, M. 2021. SA's agriculture sector – a key driver of economic growth. Future Growth. https://www.futuregrowth.co.za/insights/sa-s-agriculture-sector-a-key-driver-of-economic-growth/#_ftn1 Date of access: 27 April 2022.

Mukhala, E. 1998. Radiation and Water Utilization Efficiency by Mono-culture and Inter-crop to Suit Small-scale Irrigation Farming. *Department of Soil, Crop and Climate Sciences*, University of the Free State. (Thesis, Ph.D.).

Musshoff, O. Odening, M. & Xu, W. 2011. Management of climate risks in agriculture-will weather derivatives permeate. Appl. Econ., 43(9): 1067–1077.

National Climate Report - Annual 2020. *National Centres for Environmental Information (NCEI)*. https://www.ncdc.noaa.gov/sotc/national/202013 Date of access: 16 March 2022.

Nhamo, L., Matchaya, G., Mabhaudhi, T., Nhlengethwa, S., Nhemachena, C. & Mpandeli, S. 2019. Cereal production trends under climate change: Impacts and adaptation strategies in southern Africa. *Agriculture*, *9*(2):30.

Nhemachena, C., Hassan, R. & Chakwizira, J. 2009. Economic impacts of climate change on agriculture and implications for food security in Southern Africa. *Pretoria: Centre for Environmental Economics and Policy in Africa (CEEPA),* 33.

OBASF, 2017. Maize (Zea mays L.) *Agricultural Solutions*. https://www.agro.basf.co.za/en/Crop-Solutions/Maize/ Date of access: 24 May 2022.

Odening, M., Musshoff, O. and Xu, W. 2007 Analysis of rainfall derivatives using daily precipitation models; opportunities and pitfalls. *Agricultural Finance Review*, 67(1):135–156.

Organisation for Economic Co-operation and Development (OECD), 2021. *Agricultural Policy Monitoring and Evaluation 2021*. https://www.oecd.org/southafrica/producerandconsumersupportestimatesdatabase.htm Date of access: 14 March 2022.

Organisation for Economic Co-operation and Development (OECD). 2020. Support for agriculture. https://www.compareyourcountry.org/support-for-agriculture/en Date of access: 16 March 2022.

Podestá, G., Messina, C., Grondona, M. & Magrin, G. 1999. Associations between Grain Crop Yields in Central-Eastern Argentina and El Niño–Southern Oscillation. *Journal of Applied Meteorology* (1988-2005), 38(10):1488–1498.

Poonyth, D., Hassan, RM., Gbetibouo, GA., Ramaila, JM. & Letsoalo, MA. 2002. Measuring the impact of climate change on South African agriculture: A Ricardian approach. *A paper presented at the 40th Annual Agricultural Economics Association of South Africa Conference*, Bloemfontein, 18–20 September.

Pres, J. 2009. Measuring non-catastrophic weather risk for business. *The Geneva Papers*, 34:425–439.

Pringle, G. 2017. Maize production: Managing critical plant growth stages. *Farmers Weekly.* https://www.farmersweekly.co.za/crops/field-crops/maize-production-managing-critical-plant-growth-stages/ Date of access: 26 May 2022

Raithatha, R. & Priebe, J. 2020. Agricultural insurance for smallholder farmers. *GSMA AgriTech Programme*. https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2020/05/Agricultural_Insurance_for_Smallholder_Farmers_Digital_Innovations_for_Scale.pdf Date of access: 24 May 2023.

Rakgase, M.A. & Norris, D. 2015. Determinants of livestock farmers' perception of future droughts and adoption of mitigating plans. *International Journal of Climate Change Strategies and Management*, 7(2):191–205.

Ringler, C., Zhu, T., Cai, X., Koo, J. & Wang, D., 2010. Climate change impacts on food security in sub-Saharan Africa. *Insights from Comprehensive Climate Change Scenarios*, 2.

Rumney, E. 2021. South African farmers dream of drought cover on climate front line. *Reuters*. https://www.reuters.com/business/environment/south-african-farmers-dream-drought-cover-climate-front-line-2021-07-14/ Date of access: 24 May 2022.

Sakurai, T. & Reardon, T. 1997. Potential demand for drought insurance in Burkina Faso and its determinants. *American Journal of Agricultural Economics,* 79:1193–1207.

Santam, 2016. *Managing multi-peril crop insurance*. https://www.santam.co.za/about-us/media/agriculture/managing-multi-peril-crop-insurance/ Date of access: 3 May 2022.

Santam, 2022. *Santam Agriculture History*. https://www.santam.co.za/Agriculture/history.html

Sazib, N., Mladenova, I.E. & Bolten, J.D. 2020. Assessing the Impact of ENSO on Agriculture Over Africa Using Earth Observation Data. Frontiers in Sustainable Food Systems, (4)2020 art. https://doi.org/10.3389/fsufs.2020.509914

Shumetie, A. & Yismaw, M.A., 2017. Effect of climate variability on crop income and indigenous adaptation strategies of households. *International Journal of Climate Change Strategies and Management*.

Sihlobo, W. 2018. History of Maize Production in South Africa. *Agricultural Economics Today.* https://wandilesihlobo.com/2018/03/14/history-of-maize-production-in-south-africa-1-min-read/ Date of access: 24 May 2022.

Sihlobo, W. 2022. Agricultural input costs remain elevated, squeezing farmers' profits. *Mail & Guardian*. https://mg.co.za/opinion/2022-02-08-agricultural-input-costs-remain-elevated-squeezing-farmers-profits/ Date of access: 5 May 2022.

Sivakumar, M.V.K. 2006. Climate prediction and agriculture: current status and future challenges. *Climate Resilience*, 33:3 – 17.

Skees, J.R. & Ayurzana, E.A. 2002. Examining the feasibility of livestock insurance in Mongolia. *Policy Research Working Paper 2886*, The World Bank.

South African Grain Laboratories (SAGL), 2021. *Maize Crop Quality Report 2020 2021. https://sagl.co.za/wp-content/uploads/Maize-Crop-Quality-Report-2020-2021.pdf Date of access: 23 February 2023.*

South African Insurance Association (SAIA), 2013. *Food Security: Sustainability of Multi-Peril Crop Insurance, A Public Private Partnership.* https://www.saia.co.za/index.php?id=933 Date of access: 3 May 2022.

Southern African Development Community (SADC), 2020. *Regional Indicative Strategic Development Plan (RISDP) 2020–2030*. https://www.sadc.int/files/4716/1434/6113/RISDP_2020-2030_F.pdf Date of access: 27 April 2022.

Southern African Grain Laboratory (SAGL), 2020. *Maize Crop Quality Report.* https://sagl.co.za/wp-content/uploads/Maize-Crop-Quality-Report-2019-2020.pdf Date of access: 24 May 2022.

Spaulding A., Kanakasabai M., Hao J. & Skees J. 2003. Can weather derivative contracts help mitigating agricultural risk? In Microeconomic policy implications for Romania. *International Conference on Policy Modeling*, Istanbul, July 3–5, 2003.

Statistics South Africa (Stats SA), 2020. Fact Sheets. *Census of Commercial Agriculture 2017*. http://www.statssa.gov.za/publications/Report-11-02-01/CoCA%202017%20Fact%20Sheets.pdf Date of access: 24 May 2022.

Statistics South Africa (Stats SA), 2022. *The South African economy records a positive fourth quarter*. http://www.statssa.gov.za/?p=15214 Date of Access: 27 April 2022.

Stoppa, A. & Hess, U. 2003. Design and use of weather derivatives in agricultural policies: the case of rainfall index insurance in Morocco. *International Conference "Agricultural Policy Reform and the WTO: Where Are We Heading",* Capri, Italy.

Stringer, L.C., Dyer, J.C., Reed, M.S., Dougill, A.J., Twyman, C. & Mkwambisi, D. 2009. Adaptations to climate change, drought and desertification: local insights to enhance policy in southern Africa. *Environmental science & policy*, 12(7):748–765.

Sun, B. & van Kooten, G.C. 2015. Financial weather derivatives for corn production in Northern China: a comparison of pricing methods. *J. Empir. Finance,* 32:201–209.

Sun, Q., Miao, C., Hanel, M., Borthwick, A.G., Duan, Q., Ji, D. & Li, H. 2019. Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming. *Environment international*, 128:125–136.

Sutton-Vermeulen, D. 2021. Managing Climate Risk with CME Group Weather Futures and Options. *CME Group Weather*. https://www.cmegroup.com/education/articles-and-reports/managing-climate-risk-with-cme-group-weather-futures-and-options.html Date of access: 26 May 2022.

Taib, C.M. & Benth, F.E. 2012. Pricing of Temperature Index Insurance. *ScienceDirect*, 22–31.

Taušer J. & Čajka R. 2014. Weather derivatives and hedging the weather risks. *Agricultural Economics – Czech,* 60: 309–313.

Torriani D.S., Calanca P., Beniston M. & Führer J. 2008. Hedging with weather derivatives to cope with climate variability and change in grain maize production. *Agricultural Finance Review,* 68: 67–81.

Turvey, C. 1999. The essentials of rainfall derivatives and insurance. *Department of Agricultural Economics and Business,* University of Guelph. (Working Paper).

Turvey, C.G. 2001. Weather derivatives for specific event risks in agriculture. *Review of Agricultural Economics,* 23:333–351.

U.S. Department of Agriculture (USDA), 2020. *Risk in Agriculture*. https://www.ers.usda.gov/topics/farm-practices-management/risk-management/risk-in-agriculture Date of access: 14 March 2022.

Uys, G. 2016. Managing volatility in the agricultural market. *Farmer's Weekly*. https://www.farmersweekly.co.za/agri-business/agribusinesses/managing-volatility-in-the-agricultural-market/ Date of access: 18 May 2022.

Van Winsen, F., Mey, Y., Lauwers, L., Van Passel, S., Vancauteren, M. & Wauters, E. 2013. Cognitive mapping: a method to elucidate and present farmers' risk perception. *Agricultural Systems*, November, 122:42-52

Vedenov D.V. & Barnett B.J. 2004. Efficiency of weather derivatives as primary crop insurance instruments. *Journal of Agricultural and Resource Economics*, 29:387–403.

Viljoen, C. & Chetty, L. 2011. A case study of GM maize gene flow in South Africa. *Environmental Sciences Europe*, *23*(1):1-8.

Wang H. Holly, Young Douglas L. & Zhang Yuehua. 2013. Farmers' demand for weather-based crop insurance contracts: the case of maize in South Africa. *Agrekon*, 52(1):87–110.

Welman, J.C. & Kruger, S.J. 1999. Research methodology for the business and administrative sciences. *Oxford University: Press*.

Welman, J.C. & Kruger, S.J. 1999. Research methodology for the business and administrative sciences. Oxford University: Press.

Wiese, A. 2019. Current trends in agriculture insurance. *Farmer's Weekly*. 2019(19007):30 https://search-ebscohostcom.nwulib.nwu.ac.za/login.aspx?direct=true&db=edssas&AN=edssas.farmweek.n19007.a8&site=eds-live Date of access: 3 May 2022.

Woodard, J.D. & Garcia, P. 2008. Basis risk and weather hedging effectiveness. *Agricultural Finance Review*, 68(1):99–117.

World Bank Climate Change Knowledge Portal, 2020. *Current Climate – South Africa*. https://climateknowledgeportal.worldbank.org/country/south-africa/climate-data-historical Date of access: 16 March 2022

World Bank, 2022. Agriculture and Food. https://www.worldbank.org/en/topic/agriculture/overview#1 Date of access: 18 May 2022.

World Food Programme (WFP), 2016. *What is food security? World Food Programme*, https://www.wfp.org/node/359289 Date of access: 2 March 2022.

Xu, W., Odening, M. & Mubhoff, O. 2008. Indifference pricing of weather derivatives. *American Journal of Agricultural Economics*, 90(4):979–993.

Zara, C. 2010. Weather derivatives in the wine industry. *International Journal of Wine Business Research*, 22:222–237.

Appendix A

Correlation Matrix

Figure A1: Correlation Matrix and probabilities

Covariance Analysis: Ordinary
Date: 11/07/22 Time: 11:32
Sample: 1 63
Included observations: 63

Correlation Probability	YIELD	NOVDEC	JANFEB	JANMRCH	APRJUN
YIELD	1.000000				

NOVDEC	-0.022751	1.000000			
	0.8595	-----			
JANFEB	0.647853	0.089448	1.000000		
	0.0000	0.4857	-----		
JANMRCH	0.574760	0.092760	0.940095	1.000000	
	0.0000	0.4696	0.0000	-----	
APRJUN	-0.132652	-0.203103	-0.163903	-0.151995	1.000000
	0.3000	0.1104	0.1993	0.2344	-----

Multiple Regression - Levels

Figure A2: Multiple regression with all variables included

Dependent Variable: YIELD
Method: Least Squares
Date: 08/12/22 Time: 22:09
Sample (adjusted): 1 63
Included observations: 63 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
JAN_MRCH	0.006487	0.001213	5.346843	0.0000
APR_JUN	-0.001255	0.002153	-0.582820	0.5622
NOV_DEC	-0.001348	0.001643	-0.820777	0.4151
C	3.411098	0.460822	7.402201	0.0000

Root MSE	0.933543	R-squared	0.339985
Mean dependent var	4.644444	Adjusted R-squared	0.306425
S.D. dependent var	1.158329	S.E. of regression	0.964669
Akaike info criterion	2.827324	Sum squared resid	54.90461
Schwarz criterion	2.963396	Log likelihood	-85.06070
Hannan-Quinn criter.	2.880842	F-statistic	10.13065
Durbin-Watson stat	1.661976	Prob(F-statistic)	0.000018

Figure A3: Multiple regression with all variables and turning points included

Dependent Variable: YIELD
Method: Least Squares
Date: 08/12/22 Time: 22:11
Sample (adjusted): 1 63
Included observations: 63 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.697020	0.915655	0.761226	0.4497
JAN_MRCH	0.024227	0.005989	4.045505	0.0002
JAN_MRCH^2	-3.46E-05	1.16E-05	-2.974045	0.0043
APR_JUN	0.001489	0.007127	0.208943	0.8353
APR_JUN^2	-8.35E-06	2.84E-05	-0.294434	0.7695
NOV_DEC	0.009615	0.005332	1.803215	0.0767
NOV_DEC^2	-3.46E-05	1.51E-05	-2.287028	0.0260

Root MSE	0.841741	R-squared	0.463410
Mean dependent var	4.644444	Adjusted R-squared	0.405918
S.D. dependent var	1.158329	S.E. of regression	0.892801
Akaike info criterion	2.715534	Sum squared resid	44.63728
Schwarz criterion	2.953660	Log likelihood	-78.53932
Hannan-Quinn criter.	2.809190	F-statistic	8.060458
Durbin-Watson stat	1.567272	Prob(F-statistic)	0.000003

Figure A4: Multiple regression with all variables and dummy included

Dependent Variable: YIELD
Method: Least Squares
Date: 08/24/22 Time: 10:29
Sample: 1 63
Included observations: 63

Variable	Coefficient	Std. Error	t-Statistic	Prob.
JANFEB	0.024577	0.004018	6.116329	0.0000
JANFEB^2	-4.43E-05	1.00E-05	-4.426968	0.0000
APRJUN	-0.001712	0.005390	-0.317696	0.7519
APRJUN^2	3.04E-06	2.13E-05	0.142532	0.8872
NOVDEC	0.011819	0.004034	2.929900	0.0049
NOVDEC^2	-3.80E-05	1.14E-05	-3.323700	0.0016
DUM2006	0.902244	0.198289	4.550149	0.0000
C	0.863515	0.564424	1.529905	0.1318

Root MSE	0.628901	R-squared	0.700464
Mean dependent var	4.644444	Adjusted R-squared	0.662341
S.D. dependent var	1.158329	S.E. of regression	0.673087
Akaike info criterion	2.164282	Sum squared resid	24.91752
Schwarz criterion	2.436426	Log likelihood	-60.17487
Hannan-Quinn criter.	2.271317	F-statistic	18.37387
Durbin-Watson stat	2.006229	Prob(F-statistic)	0.000000

Multiple Regression – Logs

Figure A5: Multiple regression with all variables included

Dependent Variable: LOG(YIELD)
Method: Least Squares
Date: 08/12/22 Time: 22:10
Sample (adjusted): 1 63
Included observations: 63 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(JAN_MRCH)	0.337626	0.058490	5.772354	0.0000
LOG(APR_JUN)	-0.006275	0.035704	-0.175743	0.8611
LOG(NOV_DEC)	0.021701	0.036732	0.590798	0.5569
C	-0.388609	0.397300	-0.978124	0.3320

Root MSE	0.209256	R-squared	0.377200
Mean dependent var	1.502352	Adjusted R-squared	0.345532
S.D. dependent var	0.267287	S.E. of regression	0.216233
Akaike info criterion	-0.163531	Sum squared resid	2.758653
Schwarz criterion	-0.027459	Log likelihood	9.151230
Hannan-Quinn criter.	-0.110013	F-statistic	11.91115
Durbin-Watson stat	1.542458	Prob(F-statistic)	0.000003

Figure A6: Multiple regression with all variables and turning points included

Dependent Variable: YIELD
Method: Least Squares
Date: 09/14/22 Time: 11:34
Sample: 1 63
Included observations: 63

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-11.11206	14.80365	-0.750630	0.4560
LOG(JANMRCH)	3.349526	5.478233	0.611425	0.5434
LOG(JANMRCH)^2	-0.185316	0.520189	-0.356247	0.7230
LOG(APRJUN)	0.387879	0.806204	0.481117	0.6323
LOG(APRJUN)^2	-0.054283	0.106880	-0.507890	0.6135
LOG(NOVDEC)	1.346271	0.891461	1.510186	0.1366
LOG(NOVDEC)^2	-0.166544	0.109398	-1.522365	0.1335

R-squared	0.391184	Mean dependent var	4.644444
Adjusted R-squared	0.325953	S.D. dependent var	1.158329
S.E. of regression	0.950992	Akaike info criterion	2.841816
Sum squared resid	50.64557	Schwarz criterion	3.079942
Log likelihood	-82.51722	Hannan-Quinn criter.	2.935473
F-statistic	5.996962	Durbin-Watson stat	1.699029
Prob(F-statistic)	0.000068		

Figure A7: Multiple regression with all variables and dummy included

Dependent Variable: YIELD
Method: Least Squares
Date: 09/14/22 Time: 11:44
Sample: 1 63
Included observations: 63

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-15.80843	12.34256	-1.280807	0.2058
LOG(JANFEB)	0.641344	3.101009	0.206818	0.8369
LOG(JANFEB)^2	0.058390	0.339156	0.172164	0.8640
LOG(JANMRCH)	4.999709	6.090514	0.820901	0.4154
LOG(JANMRCH)^2	-0.485387	0.600536	-0.808257	0.4226
LOG(APRJUN)	-0.217941	0.669693	-0.325435	0.7461
LOG(APRJUN)^2	0.019177	0.088797	0.215964	0.8298
LOG(NOVDEC)	1.334741	0.707326	1.887025	0.0646
LOG(NOVDEC)^2	-0.147300	0.086976	-1.693571	0.0962
DUM2006	0.937677	0.246045	3.810995	0.0004

R-squared	0.638531	Mean dependent var	4.644444
Adjusted R-squared	0.577150	S.D. dependent var	1.158329
S.E. of regression	0.753225	Akaike info criterion	2.415713
Sum squared resid	30.06948	Schwarz criterion	2.755893
Log likelihood	-66.09497	Hannan-Quinn criter.	2.549508
F-statistic	10.40267	Durbin-Watson stat	2.306273
Prob(F-statistic)	0.000000		

Figure A8: Previous year's rainfall figures

Dependent Variable: YIELD
Method: Least Squares
Date: 09/17/22 Time: 09:42
Sample (adjusted): 2 63
Included observations: 62 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.650021	0.595312	2.771692	0.0076
NOVDEC	-0.001246	0.001337	-0.932186	0.3553
JANFEB	0.023748	0.004487	5.292625	0.0000
JANFEB^2	-4.28E-05	1.11E-05	-3.844160	0.0003
APRJUN	-0.002738	0.001690	-1.620642	0.1108
ANNUAL(-1)	0.000528	0.000706	0.747380	0.4580
DUM2006	0.931539	0.220155	4.231290	0.0001

Root MSE	0.690147	R-squared	0.631626
Mean dependent var	4.672258	Adjusted R-squared	0.591440
S.D. dependent var	1.146379	S.E. of regression	0.732751
Akaike info criterion	2.321982	Sum squared resid	29.53078
Schwarz criterion	2.562143	Log likelihood	-64.98145
Hannan-Quinn criter.	2.416275	F-statistic	15.71748
Durbin-Watson stat	2.093457	Prob(F-statistic)	0.000000