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

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Abstract

The study investigates the potential of weather derivatives to mitigate agricultural risk factors. Specifically, it examines the feasibility of rainfall options as a risk management tool in hedging yield risk for maize farmers in the North-Western Free State province of South Africa. The correlation between rainfall and crop yield is established by examining data on maize yield over a 20-year period. Results indicate that rainfall during January and February has the most significant impact on maize production. By using a Yield-at-Risk analysis, the study determines that a minimum rainfall level of 135mm during January and February is needed to ensure a good crop. The results show that rainfall options can be financially viable in South Africa, particularly in the water table region of the North-Western Free State. Although the study admits that farming profitability may not significantly improve, it shows that downside risk can be limited while still achieving a 30% profit on input costs, as offered by the region.

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

JEL classification: O13, Q12, Q13, and G13

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1. Introduction and background

In developing economies like South Africa, agriculture holds immense significance as the foundation for economic growth. With its strong linkages to input suppliers and the agro-processing sector, agriculture plays a pivotal role in driving employment and economic multipliers throughout the country. While contributing 6% (combined with agro-processing) to South Africa's gross domestic product (GDP), its impact on the local economy goes beyond mere numbers (Delport, 2022). However, the agricultural sector is not without challenges. Volatility stemming from climate change, political actions, and social changes creates fluctuations in yields, affecting both local and global supply dynamics. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), countries whose economies heavily rely on agriculture are more vulnerable to the effects of climate change compared to countries with a smaller agricultural contribution. This is particularly relevant for Southern African economies, which are sensitive to the direct consequences of climate change, primarily due to their dependence on rainfed agriculture (Matimolane et al., 2022). Countries in which agriculture contributes a larger share to total production face a larger exposure to the impacts of climate change than countries with a lower share of agricultural contribution to their economy (IPCC 2014). Southern African economies are sensitive to the direct impacts of climate change due to their dependence on rainfed agriculture. Geopolitical influences, government policies, and global trade tensions further contribute to the complex and dynamic nature of the agricultural landscape. Moreover, the diverse range of crops and food types, each with its own fragmented supply chains, adds complexity to the sector. Environmental factors also come into play, exerting influence on regional and yearly production. In light of these key features, understanding and effectively managing the risks associated with South Africa's agricultural landscape becomes crucial for the sustainability and growth of the sector.

Risk is an inherent part of agriculture, and farmers have long sought ways to reduce uncertainties in both production and marketing processes. The abolishment of the marketing boards and the advent of the futures market in South Africa enabled farmers to effectively hedge their price risk. However, weather uncertainty, particularly in terms of temperature and precipitation, has become a major concern for dryland crop farmers, and climate change has further exacerbated this risk (Sun et al., 2019).

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. This cost disparity is primarily driven by high fertilizer expenses, which are on average 80% higher as compared to the leading maize export countries (Grain SA, 2020). Additionally, South Africa's heavy reliance on agricultural input imports (Campbell, 2020) makes it particularly sensitive to currency fluctuations. The recent depreciation of the Rand against the US Dollar has further exacerbated rising input costs, with an increase of 35.5% from the 2021/22 to the 2022/23 marketing season (Rudisteibach, 2022), placing additional strain on the profitability of maize production in the country. In this context, it becomes crucial to explore alternative methods that could enable producers to hedge their yield risk exposure. The combination of lower yields and high input costs can significantly impact the financial survivability of farms. Therefore, it is essential to identify strategies that not only address price risk, but also effectively manage yield risk.

Rainfall plays a pivotal role in crop growth, making it a critical factor that greatly influences agricultural yield (GCIS, 2017). In comparison to the leading maize-producing countries, South Africa receives relatively low average annual rainfall (FAO, 2020), thereby facing inherent limitations regarding this vital input for agriculture (Grain SA, 2020). 95.4% of the total amount of maize planted in South Africa during 2020 was grown on dry land (CEC, 2020). This highlights a significant vulnerability in South African agriculture, as a substantial portion of the sector is highly dependent on the capriciousness of rainfall and thus exposed to considerable yield risk. Dryland maize farmers in South Africa are dependent on the frequency and the timing of rain for good yields. Given the uncertainties surrounding weather conditions and the escalating input costs, crop farmers in South Africa face mounting pressure on their profitability. It is, therefore, imperative to explore alternative means through which farmers can safeguard themselves against adverse weather that results in yield losses.

Currently, two methods are available for farmers to protect themselves against yield risk: Multi-peril crop insurance (MPCI) and weather derivatives. MPCI products are offered in South Africa, but their adoption among farmers remains low primarily due to the high cost associated with these products (Wiese, 2019). In 2019, the MPCI market for crop and harvest-related insurance represented 30 % of the value of all crops, with a market penetration of a mere 17% of planted crops (Wiese, 2019). The South African Insurance Association has highlighted the expensive premium if MPCI, making it challenging for farmers to afford due to the cost-price squeeze prevalent in the agricultural sector (GreenCape, 2018).

As an alternative solution, weather derivatives have emerged in the mid-1990s as a tool to mitigate weather risk (Xu et al., 2008). Carter et al. (2014) identify index-based insurance as the best option for the uninsured farmers, providing them with access to formal insurance in response to market inefficiencies that are apparent in South Africa and other parts of Africa. Unlike traditional loss-based crop insurance, weather derivatives allow farmers to reduce crop yield risk without the systemic risk and high administrative expenses associated with it (Wang, Young Douglas & Zhang, 2013). Although weather derivatives are not commonly used in South Africa, they hold significant potential, considering global market trends in transferring weather-related crop risks.

While rainfall derivatives are recognised as a valuable risk management tool internationally, South African farmers have been slow in embracing their utilization. This paper focuses on rainfall options as an alternative hedging strategy for farmers to effectively mitigate yield risk. Rainfall derivatives includes various financial contracts, including forward contract agreements, swaps, futures contracts and options on futures contracts, which allow participants to transfer the risk associated with insufficient or excessive rainfall. This study, however, solely concentrates on rainfall options as a risk management tool. The reason to focus solely on rainfall options is motivated by their cash flow characteristics, which closely corresponds with that of MPCI, thereby facilitating a more straightforward comparison between the two. This study examines the usage of rainfall options to assess their potential as a viable alternative to MPCI for farmers in managing rainfall-related uncertainty and analyse their effectiveness in hedging yield risk.

With the increasing difficulty for farmers to achieve sustainable profit levels, coupled with the cost-price-squeeze and variability in annual yields, exploring new approaches becomes imperative. To assess the potential viability of weather derivatives for farmers, this study evaluates the price of the weather derivative in comparison to its effectiveness in reducing yield risk and the correlation of its payoffs with losses. By considering the historical input costs of white maize in the North-Western Free State area spanning from 2000 to 2021, the profitability of farmers is analysed. Subsequently, the profit margins are juxtaposed with various seasonal scenarios to evaluate if the implementation of rainfall options can enhance the overall financial position of maize farmers in the North-Western Free State.

2. Literature review

2.1 Agricultural risks

Agriculture plays a critical role in global food security and economic stability. According to the World Bank (2022), agriculture accounted for four per cent of global GDP in 2018, and in some least-developed countries, it can account for more than 25 per cent of the GDP. The inherent uncertainty associated with agricultural production, however, poses significant challenges for the economy at large. Yield risk can have profound implications for food production, income stability, and overall agricultural stability. The increasing frequency and intensity of climate change-related events recently have further amplified the importance of managing yield risk effectively.

The literature on agricultural risk management has explored various strategies and instruments to mitigate the adverse effects of yield risk. 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 or various geographical areas.

Farmers must weigh the financial implications of each of these options against their risk aversion behaviour, their perception of risk and their competency and risk anticipation skills (Girma, et al., 2023 and Adnan et al., 2023). 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 crop. While these instruments have proven useful in addressing certain types of risks, they may not always adequately capture the specific nature and dynamics of yield risk associated with rainfall patterns.

This literature review aims to delve into a specific aspect of agricultural yield risk management by focusing on the use of rainfall options as a hedging tool. Rainfall options offer a unique opportunity to tailor risk management strategies to the particular challenges posed by rainfall variability, which has a direct impact on crop yields. By analysing the existing literature, this review seeks to provide an understanding of the effectiveness, limitations, and potential of rainfall options as a risk management tool for maize farmers.

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 tried 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.

2.2 Understanding yield risk and its relationship with climate change

Yield risk encompasses the uncertainties associated with factors such as weather conditions, pests and diseases, soil type and quality and management practices. The consequence of yield risk is twofold, both economic and environmental. The economic consequence lies in its potential to disrupt agricultural productivity and food security. Yield risk directly affects the income stability of farmers. A change of 0.5 ton per hectare can result in a change in income of 0.95% (based on the maize budgets of GrainSA, 2023 for the North-Western Free State province). The environmental consequence lies in soil erosion, water pollution and biodiversity loss, which affects the long-term sustainability of agricultural systems. In the context of climate change, the consequence of yield risk becomes even more noticeable.

Climate change is causing changes in temperature patterns, altering precipitation and weather systems, and increasing the frequency and intensity of extreme weather events (Werndl, 2016). Dell, Jones, and Olken (2008) demonstrate that climatic variability has a negative impact on economic growth in developing countries. This is supported by Dellink (2014) that confirms the negative impact of climate change on the global GDP and regional economies, particularly in regions such as South and Southeast Asia. The negative impacts of climate change are projected to be more pronounced in countries that are poorer, hotter and in areas with lower elevations (Tol, 2018). In support of this, Bansal (2016) presents a temperature-augmented long-run risk model that verifies the relationship between temperature and economic risk.

According to Aydinalp and Cresser (2008), climate change has varying impacts on role players in agriculture, some benefit from increases in production, while others will experience decreases. 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. Climate change will result in a decline in agricultural productivity in most parts of Southern Africa due to higher temperatures and increased rainfall variability. Maize production is expected to decrease by as much as 8 – 38% under certain climate change conditions (Choruma, et al., 2022). Decreased maize production in South Africa due to climate change were verified by studies by Olabanji et al. (2022) and Samuel and Sylvia (2019). A study by MacCarthy et al (2021) found that maize is the most vulnerable cereal to climate change.

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. Weather derivatives represent a new tool for non-catastrophic weather risk management, with numerous advantages over alternative management tools.

2.3 Weather derivatives and insurance products

Weather derivatives are financial instruments that can be used by participants to reduce risk associated with adverse or unexpected weather conditions. The value of a weather derivative is based on an index of weather-related variables, such as temperature, wind or precipitation. 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). In the context of crop insurance, weather derivatives help reduce the perceived information asymmetry associated with crop insurance, wherein farmers often have more information about their individual risk than insurers.

Weather derivatives cover low-risk, high-probability occurrences, whereas weather insurance, in general, covers high-risk, low-probability occurrences, as defined in a fully personalised 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 or rainier summer (Buckley et al., 2002). In addition to weather derivatives, insurance products tailored specifically for the agricultural sector, such as multi-peril crop insurance, play a vital role in managing yield risk. Literature suggests several advantages of weather derivatives and insurance products in agricultural risk management. They provide farmers with a degree of financial certainty and enable better planning and decision-making. These instruments can also facilitate access to credit, as they can serve as collateral.

The goal of insurance is to lower financial risk and make unintentional loss controllable. It is accomplished by paying an insurance premium, to a professional insurer, who then assumes the risk of a significant loss and commits to paying out the larger amount in the event of such a loss (Mishra and Mishra, 2008). Farmers purchase insurance to offset the negative economic impacts of adverse weather conditions. 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. 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, one challenge lies in distinguishing between crop losses caused by uncontrollable factors like drought and those resulting from unacceptable farming practices (Santam, 2016). As a result, farmers must adhere to a set of norms and rules to qualify for coverage, including acceptable emergence dates and appropriate plant density (Santam, 2016). Essentially, the practices considered the proven norm for the specific area must be followed.

Crop insurance accounts for a small portion of the insurance market in South Africa. The agricultural insurance market for crop- and harvest-related insurance in primary agriculture is approximately R1.5 billion in terms of premiums (Wiese, 2019), which account for roughly 30 per cent of the total value of all crops in the country. Market penetration of MPCI in the commercial sector is only 17 per cent of the planted surface area and is negligible in the small-scale sector (SAIA, 2013). The low market penetration of MPCI in South Africa can be attributed to expensive premiums due to high weather event volatility, particularly frequent droughts, as well as the high transaction costs with offering insurance products to a wide distribution of clients in remote areas.

Weather derivatives are currently less common. 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 characterised by increased variability and frequency of extreme weather. According to the literature, weather derivatives can be beneficial tools for managing yield risk, although certain considerations need to be considered. Musshoff and Odening (2011) determined that rainfall options may be able to reduce the risk associated with rainfall variability. The effectiveness is questioned due to basis risk. In his analysis of the effectiveness of weather derivatives as a primary insurance tool for maize, cotton, and soybean production in the US, Filonov and Vedenov (2011) discovered that the optimal structure of weather derivatives fluctuates across crops and regions. Overall, the articles indicate that weather derivatives can be a useful tool for reducing yield risk, but attention must be taken in the design of the derivatives and the specific risks they address must be considered. The payoff structure of an exchange-traded weather derivative is the same as that of an insurance product. A large amount of risk remains with the producer when using weather derivatives because individual yield variations are not correlated in general with the relevant weather variable (Woodard and Garcia, 2008). The risk also increases due to the geographical basis risk.

Rainfall options are derivative instruments that enable participants to hedge against the variability in rainfall. It enables farmers, agribusinesses and other stakeholders to mitigate the financial impacts of adverse weather conditions, such as drought or excessive rainfall (Geyser & Van der Venter, 2001), which can significantly impact crop yields.

Several studies have examined the use of rainfall options as a means of hedging yield risk in agriculture. These studies consistently demonstrate the potential effectiveness of rainfall options in managing weather-related risks and reducing yield volatility. A study by Vashisht (2020) explores the feasibility of using rainfall derivatives as a hedging tool for rainfall risk in India. He found that rainfall options have the potential to provide valuable risk management solutions. Manfredo and Richards (2005) suggests that options can be used in combination with linear pay-off instruments to minimize basis risk associated with the non-linear relationship between weather and yields. Cyr et al (2010) provides an example of how a rainfall option can be designed to hedge the risk of too little or too much rain. The study did not address the economic viability and feasibility of implementing weather derivatives in vineyard operations. Pelka and Musshoff (2013) finds that mixed index-based weather derivatives have a significantly higher potential to reduce the risk of winter wheat revenues than simple index-based weather derivatives. They unfortunately failed to comprehensively compare the effectiveness of weather derivatives with other risk management strategies commonly used in arable farming. Assessing the performance of weather derivatives against traditional methods, such as crop diversification or crop insurance, would provide a better understanding of their hedging effectiveness.

2.4 Basis risk and its relevance to rainfall options

Basis risk is a crucial consideration in the utilization of rainfall options for yield risk hedging. Basis risks arise when the derivative price and the underlying instrument do not move in the same direction (Geyser & Van der Venter, 2001). This happens when the actual rainfall conditions experienced by the farmer may not perfectly align with the base station specified in the rainfall option contract. Basis risk 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). Woodward and Garcia (2004) found that although basis risk can be significant, it should not prevent usage. Their study found that basis risk is more pronounced in precipitation derivatives than temperature derivatives. Mixed indices composed of several weather variables can be used to negate the effects of basis risk (Pelka & Musshoff, 2013). A study by Odening and Musshoff (2007) analysed the hedging effectiveness of rainfall options and the role of geographical basis risk by making use of a daily precipitation model. They compared their results against the simpler pricing methods such as the burn analysis and the index value simulation. They found that the choice of statistical approach may lead to differences in the estimation results. Their study only focused on a single risk event, even though stress events that happen in combination often have amplified negative effects than stress events happening independently.

The existing literature supports the use of weather derivatives, particularly rainfall options, as a tool to hedge yield risk. However, a gap in the previous studies is the absence of an economic assessment regarding the feasibility of using rainfall options, as opposed to MPCI, as a hedging tool for maize farmers in the North-Western Free State region. By addressing this gap, the article aims to contribute valuable insights and answers the pressing question whether rainfall options is more suitable as a yield risk tool than MPCI.

3. Conceptual framework

The empirical component of this study used a quantitative research approach to assess the viability of rainfall options as a yield risk management tool. Purposely, time-series data was used to determine the optimal rainfall levels during the maize growing period for achieving optimal profitable yields. The focus area was the North-Western Free State region where the growing period of maize extends from late October to March from 2000 to 2021, with typical planting commencing in the latter half of November.

The analysis was divided into two steps. Firstly, the study aimed to identify specific rainfall thresholds (either too little and/or too much) that negatively impact maize yield in the North-Western Free State. To achieve this, the relationship between rainfall and yield was established using recorded data from three designated weather stations: Bultfontein, Wesselsbron and Hoopstad, which collectively represent the chosen region.

The second important aspect involved determining the pricing of the rainfall derivative. This was necessary to determine the financial feasibility and profitability of rainfall options compared to regular crop insurance. Secondary data were obtained from reputable sources such as the South African Weather Service, SAGIS, Grain SA, Senwes, and the Johannesburg Stock Exchange. Descriptive statistics were used to summarize the data, correlations were calculated to examine relationships, and regression analysis estimated to identify statistically significant relationships.

The findings of the research were used to determine the relationship between yield and rainfall, enabling the pricing of a rainfall option. Scenario analysis was performed to determine whether farmers would have been in a better financial position had they made use of rainfall options as a hedging tool against yield risk.

3.1 Empirical model

Climate variability accounts for up to 80% of the year-to-year variability in crop yields in many countries (Sivakumar, 2006). It is 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 critical pollination stage. Excessive heat can cause the premature death of pollen before successful pollination can take place. In this study, it is assumed that temperature is indirectly reflected in rainfall data since periods of low rainfall are normally associated with periods of higher temperature. The yield level necessary to break even was required to determine the Value-at-Risk (VaR) and the percentage of the crop that needs to be hedged.

VaR is a financial tool regularly used to assess the level of risk associated with an investment (CFI, 2022). Although initially developed for financial institutions, VaR has found applications beyond the domain of finance, including the agriculture sector (Gloy & Baker, 2001). Markedly, Manfredo and Leuthold (2001) use VaR methods to estimate the market risk of cattle feeders. In this study, we leverage the financial concept of "Value-at-Risk" and adapt it to the agricultural context to calculate a metric called "Yield-at-Risk" (YaR) (Geman, 2015). The YaR quantifies the probability of downward deviations from the yield trend. By incorporating a sensitivity analysis, we assess the farmer's vulnerability to yield fluctuations. We determined the expected profit by using historical input costs, average prices and average yields (data was obtained from GrainSA).

We broaden the scope of the use of VaR concepts by applying it to agriculture, establishing a framework for assessing yield risk and understand the potential impact of varying factors on farmers' profitability. This approach allows for a more comprehensive assessment of risk in agricultural decision-making, ultimately supporting methods for yield management that are more well-formed. This model helped determine how sensitive the farmer is to yield, for his farm to still be financially feasible. The model provided the percentage he or she needs to hedge. The Yield-at-Risk is calculated as follows:

$$YaR = X * \sigma * \sqrt{(1-\rho)} * z \tag{1}$$

- X denotes the ranked profit level, ranging from low to high
- σ is the standard deviation of the profit levels(measures the variability of profits)
- ρ is correlation coefficient
- z is the critical value corresponding to the desired confidence level

This equation enabled us to estimate the potential loss in profit per hectare at a specific confidence level, considering the variability in profits, the correlation with yield and the desired level of confidence.

4. Data and Results

4.1 Relationship between rainfall and yield

Except for the overall impact of rainfall on yield, it was important to determine which rainfall period has the greatest impact on yields. The reason for determining it is to shorten the duration of a rainfall option, utilising it during the most critical period, to make the rainfall option more affordable. The Black and Scholes option pricing model shows that there exists a relationship between the time to maturity and the price of an option – the longer the time to maturity, the more expensive an option (all other variables held constant).

To analyse the relationship between rainfall and yield, the average monthly rainfall each season will be compared to the corresponding average yield. This analysis will reveal the relationship between rainfall and yield, as well as identifying the critical stages of the growing season when the plant is most vulnerable to rainfall fluctuations impacting yield.

The monthly rainfall data for Hoopstad, Bultfontein and Wesselsbron[1] was obtained from the South African Weather Services and Senwes, imported into Excel for analysis. The average seasonal maize yield data was obtained from the Department of Agriculture, Land Reform and Rural Development (DALRRD), also imported into Excel. Data for the three stations recorded over the 21 year period are pooled into one sample as basis for pooled regressions. The resulting 63 observations allows for more meaningful tests of statistical significance than what would be the case if we only employed time series data over 21 years.

Yield per hectare serves as dependent variable. Rather than regressing yield on the total rainfall for the season (measured from November to June), rainfall as explanatory variable (measured in millimetres) 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, in this way the kernel forming stage is now only represented by rainfall for January to February. Quadratic versions the rainfall variables are also included to test for relationships that are not only linear. In this way a potential maximum point can be calculated – and more specifically the minimum and maximum amount of rainfall needed to obtain a certain yield. 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. Regressions were estimated with data both

1. These stations are situated in the study area and data were available for the same time frame as yield

in levels and logarithmic format – however only the results for multiple regressions in levels are reported in Table 1.

Table 1. Multiple regressions explaining maize yield

	Only yield and three different periods included Equation 1		Turning points of the different periods included Equation 2		February to March and Dummy of 2006 included Equation 3	
	Variables in levels					
	Estimated coefficients	Probability	Estimated coefficients	Probability	Estimated coefficients	Probability
C	3.411098	0.0000	0.697020	0.4497	0.863515	0.1318
JanFeb					0.024577	0.0000
$JanFeb^2$					-4.43E-05	0.0000
Janmrch	0.006487	0.0000	0.024227	0.0002		
$JanMrch^2$			-3.46E-05	0.0043		
AprJun	-0.001255	0.5622	0.001489	0.8353	-0.001712	0.7519
$AprJun^2$			-8.35E-06	0.7695	3.04E-06	0.8872
NovDec	-0.001348	0.4151	0.009615	0.0767	0.011819	0.0049
$NovDec^2$			-3.46E-05	0.0260	-3.80E-05	0.0016
Dum2006					0.902244	0.0000
R^2	**0.339985**		**0.463410**		**0.700464**	
Obs(n)	**63**		**63**		**63**	

Source: Compiled by author

Equation 1 regresses yield (in ton per hectare) for three rainfall periods: November – December, January – March and April – June. Equation 2 includes squared versions to test for potential quadratic relationships and turning points. Equation 3 replaces the period January – March with the shorter period of January – February.

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 was included in the regression, the R^2 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 all included; the dummy variable of 2006, the use of biotech crops showing a significant increase in South Africa (James, 2009), 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.

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 be more beneficial for a farmer to only hedge during these two months, as this period is not only the most crucial for kernel forming but also a shorter period to hedge, making the rainfall option more affordable.

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

4.2 Crop profitability

Crop profitability helps to establish if maize is a profitable crop for the North-Western Free State. Figure 2 below indicates the historical input and producer prices of maize each season over the past 20 years (Grain SA, 2022).

According to Figure 1, the overall cost of maize production (consisting of input cost and fixed cost) has consistently risen every year since 2000. The increase can be attributed to higher input costs and inflation. On the other hand, there has been a notable improvement in yield of maize per hectare over the same period. This can be attributed to better farming practices, improved technology and the introduction of genetically modified crops. Figure 1 further shows that the marketing seasons of 2004/05 and 2015/16 were unprofitable for maize cultivation in this region. Profits of maize farming is determined by subtracting the total cost from the total income, which is calculated as the yield multiplied by the farmgate price. This corresponds with Figure 1, where it is clear that recorded rainfall was below the average for the region by 528mm per year.

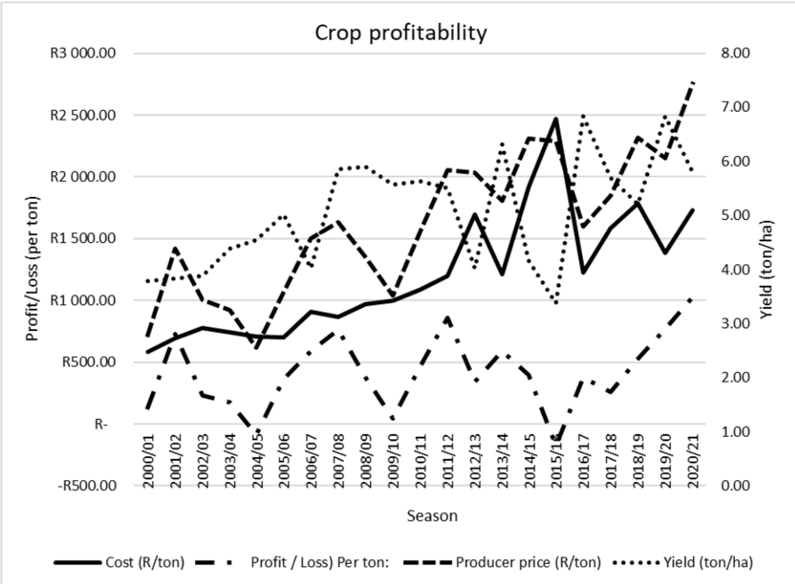

Figure 1. Crop profitability graph in the Northern-West Free State

Increases in input costs over the last decade confirm the fact that maize is less profitable when yields are low. Figure 1 shows that when yields are low, profits are low, as 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 and the yield also increased during that period. The facts emphasise the importance of mitigating yield risk due to the cost-price-squeeze farmers experience.

4.3 Sensitivity analysis for determining profitable yield for maize

In the previous sections, the relationship between yield, 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 farmers need to harvest with the current input cost at hand to know if maize will be a profitable crop option.

To determine the ideal yield necessary for maize to be a profitable crop, data was analysed from 2006 when biotech crops were introduced to improve yields. The profit or loss per hectare were calculated by subtracting the total cost per hectare from the product of yield per ton and the farmgate price. Table 2 indicates that farmers in the North-Western Free State, in the water table soil area, have an average profit margin of 39% 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

Table 2. Profit on input cost margins

Marketing Season	Total cost (per/ha)	Yield (ton/ ha)	Farmgate price (R/ton)	Profit or Loss per ha	% Profit/Loss on Total cost
2006/07	R 3 661,56	4,02	R 1 502,91	R 2 380,14	65%
2007/08	R 5 087,84	5,85	R 1 632,83	R 4 464,22	88%
2008/09	R 5 717,78	5,9	R 1 347,70	R 2 233,65	39%
2009/10	R 5 548,60	5,57	R 1 041,66	R 253,45	5%
2010/11	R 6 140,11	5,63	R 1 559,88	R 2 642,01	43%
2011/12	R 6 590,07	5,5	R 2 057,52	R 4 726,29	72%
2012/13	R 6 821,68	4,03	R 2 035,79	R 1 382,55	20%
2013/14	R 7 643,75	6,32	R 1 802,59	R 3 748,62	49%
2014/15	R 7 959,68	4,16	R 2 311,46	R 1 655,99	21%
2015/16	R 8 313,86	3,37	R 2 290,00 -	R 596,56	-7%
2016/17	R 8 376,05	6,84	R 1 599,00	R 2 561,11	31%
2017/18	R 9 052,46	5,7	R 1 847,00	R 1 475,44	16%
2018/19	R 9 307,87	5,21	R 2 316,58	R 2 761,51	30%
2019/20	R 9 465,13	6,83	R 2 154,50	R 5 250,11	55%
2020/21	R 10 034,49	5,81	R 2 751,88	R 5 953,93	59%

Source: Compiled by author

on input cost. The farmer wants to improve on 39 per cent profit on input costs because this is what the area offers; looking at historical numbers, this can be seen as the break-even price because this area consists of high potential soil. If a yield of 5.38t/ha is harvested, a profit margin on an input cost of 39% is reached. 5.38t/ha is the critical yield level, ideal for what the area can offer.

With the average yield of 5.38t/ha, YaR will help to determine the minimum 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-organises actual historical returns, putting them in order from worst to best. It then assumes that history will repeat itself, from a risk perspective.

Table 3. Historical Yield-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

Source: Compiled by author

Using the historical YaR method, Table 3 indicates the different confidence levels, 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 3 indicates that at a 99 per cent confidence level, chances are that 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 an input cost of 39 per cent.

4.4 Rainfall levels that impact yields

Section 4.1 revealed that the most significant months 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. The limited number of independent weather stations is a problem in South Africa, as basis risk still occurs. The onset and the time difference for when rain falls, happens to fall outside the scope of this study and can be included in further studies.

Equation 3 in Table 1 is used to forecast the expected yield for varying levels of rainfall for the period January and February. This is needed to determine the rainfall needed in January to February, to harvest 5.0t/ha and still be able to make a profit of 39 per cent on input cost. The average rainfall for the other two periods included in equation 3, AprJun and NovDec, are used to forecast the yield at different combined rainfall levels for January and February (see Annexure Table A1). The average yield is 5.51t/ha, while the average rainfall for the period January to February is 175.14mm.

If 5.08t/ha needs to be harvested to make a 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; 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 yield is 275mm.

4.5 Pricing rainfall options

Although the Historical Burn Analysis approach is frequently used to assess event-specific risk such as weather related risk and to compute climate index insurance (Taib & Benth, 2012), the Black-Scholes (BS) formula was used to determine the premium based on the rainfall index. The reasons for choosing the Black-Scholes formula are as follows:

- The BS formula is a widely recognized and extensively used pricing model and its application to options pricing has been well-established and validated over time. The formula incorporates factors such as the underlying asset's price (for this article the rainfall level), time to maturity, volatility, and the strike price (rainfall level).
- The BS formula provides a systematic approach to valuing options, assuming an efficient market.
- Black-Scholes, as a 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. Therefore, the Black Scholes formula can be used to price weather derivatives, as the option will only be exercised at the end of the indexed period. [2]

The BS formula aligns with financial practices, enhancing the transparency and comparability of option pricing within the agricultural risk management context.

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

$$P = Ke^{-rT}N - d_2 - S_0N(-d_1) \tag{2}$$

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, 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, and $N(-d_1)$ 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

2. The forecasting is done based on the estimated equation 3 reported in Table 1 with a relative good R2 of 0.70: Yield = 0.864 + 0.025 JanFeb – 0.0004 JanFeb^2 – 0.002 AprJun + 0.00003 AprJun^2 + 0.012 NovDec -0.00004 NovDec^2 + 0.902. Yield was forecasted over a range of potential rainfall during the period JanFeb; while the historic average rainfall for AprJun and NovDec was used in the forecast. The estimated yields are reported in the Appendix.

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. T is the annualised volatility of the 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; and $N(-d_1)$ is the cumulative density function of the normal distribution of D_2.

It is assumed that when the option reaches intrinsic value and is realised, the pay-out will be determined by the difference in yield according to the rainfall amount achieved. The scale for this will be the forecasting of rainfall reflected in Appendix A. 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.

4.5.1 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 provide an average yield of 4.876182t/ha according to the yield forecasting table (see Appendix). 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 rainfall that actually rained, together with the yield forecasting table, will 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 4.5).

If it only rained 120mm in January and February as assumed, the farmer will only harvest 4.876182t/ha according to Table 5. 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 pay out 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 (S0) will stay 175mm because it is the average rainfall for this period and the strike value (K0) 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 4.5).

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 pay out 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 4.5).

According to the assumptions that it will only rain 120mm for January and February, the difference in yield still remains 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.

4.5.2 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 Appendix). 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 will be used to determine the payout.

Scenario 1 – At the money (ATM) call options

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 4.5.1).

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 payout 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.

Scenario 2 – 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 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 4.5.1).

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 it will give the buyer a payout 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 payout of R1 824.57 and a profit that will be the same as the payout of R1 824.57 if the option is exercised. The reason is that the option is so far out of the money the premium cost is R0, and 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 change, and is not dependent on the SAFEX price. The payout price will only change if the SAFEX price changes; higher producer prices mean higher pay-outs.

4.6 Rainfall options compared to agriculture insurance

Rainfall options and insurance are 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 that provide protection against rainfall for maize; 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, the option pays out in 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 4.5.1, for the options with insurance, and it 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 Northern-West 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; as is 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, while options only the part that will be lost due to the unpredictability of rainfall – the difference in yield achieved.

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 do not depend on the producer price to determine their premium price.

5. Limitations and recommendations for further studies

The data in this research only followed a time frame of twenty years. As more data are recorded, 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 maize futures prices.

It is also recommended for further studies to consider a solution for basic 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 nearest reference weather station.

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 practise, it is important to focus on independent weather data at specific locations. This will mean more weather stations on farms for the data to be more accessible. 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 reliable.

Rainfall and yield were distributed throughout the district. Although the average rainfall damage in 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, were ignored. If the majority 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 practise 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.

6. Conclusion

This study examined the feasibility of weather derivatives in the context of South African agriculture and offers a suitable approach to employing options on rainfall as a yield risk management tool. The goal of the weather derivatives implementation, like any other risk management tool, is to reduce the volatility of revenues and/or costs caused by noncatastrophic weather volatility. The purpose of weather derivative payouts is to compensate for lost revenues and extra costs caused by bad weather. 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 greatly benefit from the adoption of weather derivatives to control yield risks on agricultural markets.

This study confirmed that rainfall options can be financially feasible in South Africa, especially in the water table soil region in the Northern-West Free State. Scenario analysis showed that farmers can hedge themselves against lower yields at a cost of R79.99, compared to R264.00 using MPCI. The farmer can obtain additional protection against too much rain by entering a long call rainfall option. No insurance product currently provides the same protection to maize farmers in South Africa.

The study clearly showed that rainfall options are a method farmers can utilise in minimising yield risk.

Biography notes

Johandri de Necker currently serves as an export coordinator at Van Doorn South Africa (Pty) Ltd. A proud alumna of North-West University Potchefstroom, my upbringing on a farm cultivated an early fascination with the agriculture sector, ultimately shaping my career choice. My keen interest in agriculture extends beyond farming to encompass the entire supply chain. Before assuming the role of Agri-based Product Export Coordinator, I earned a M.Com in Risk Management at the North-West University. In my leisure time, I enjoy engaging in sports, cherishing moments with family and friends, and indulge in life's finer pursuits.

Mariette Geyser holds the position of Senior Lecturer in Agricultural Economics at the School of Economic Sciences on the Potchefstroom campus of North-West University. Her academic journey includes earning a D.Com. in Financial Management from the University of Pretoria and an M.Com. in Business Economics from North-West University. With a diverse background, Mariette previously lectured at the University of Pretoria and gained experience in the corporate sector. Her research focus revolves around climate-smart agriculture and derivative instruments. Mariette is the author of the book "Long and Short of Futures Markets: SAFEX, Grain Hedging and Speculation" and serves as a co-editor of the renowned Finance and Farm Management textbook of Standard Bank.

Anmar Pretorius is a Professor of Economics at the School of Economic Sciences, Potchefstroom campus, North-West University. Previously she lectured at the UFS, UNISA and Monash South Africa. She obtained a D.Com. (Economics) from the University of Johannesburg, with a thesis exploring South Africa's financial market integration. Before her PhD, she obtained an M.Com. in Economics from the University of the Free State. Her research interests are in financial economics and applied economics. More specifically, she enjoys analysing higher frequency financial time series data. A more recent research focus deals with the advanced emerging markets, a group including South Africa.

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Conflict of interest

The authors declare no conflict of interest.

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Annexure A

Table A1: Yield forecast at different levels of rainfall

January to February rainfall (mm)	Yield (t/ha)	January to February rainfall (mm)	Yield (t/ha)
115	4.80535	315	5.91095
120	4.876182	320	5.893182
125	4.9448	325	5.8732
130	5.011202	330	5.851002
135	5.07539	335	5.82659
140	5.137362	340	5.799962
145	5.19712	345	5.77112
150	5.254662	350	5.740062
155	5.30999	355	5.70679
160	5.363102	360	5.671302
165	5.414	365	5.6336
170	5.462682	370	5.593682
175	5.50915	375	5.55155
180	5.553402	380	5.507202
185	5.59544	385	5.46064
190	5.635262	390	5.411862
195	5.67287	395	5.36087
200	5.708262	400	5.307662
205	5.74144	405	5.25224
210	5.772402	410	5.194602
215	5.80115	415	5.13475
220	5.827682	420	5.072682
225	5.852	425	5.0084
230	5.874102	430	4.941902
235	5.89399	435	4.87319
240	5.911662	440	4.802262
245	5.92712	445	4.72912
250	5.940362	450	4.653762
255	5.95139	455	4.57619
260	5.960202	460	4.496402
265	5.9668	465	4.4144
270	5.971182	470	4.330182
275	5.97335	475	4.24375
280	5.973302	480	4.155102
285	5.97104	485	4.06424
290	5.966562	490	3.971162
295	5.95987	495	3.87587
300	5.950962	500	3.778362
305	5.93984		
310	5.926502		