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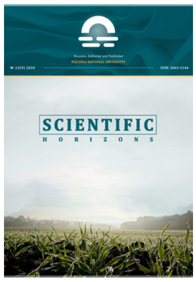

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Weather derivatives and maize yield risk in the South African agricultural market

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Abstract. Climate variability significantly impacts agricultural productivity, rendering risk management tools essential for stabilisation of yields and financial returns. The study aimed to evaluate the effectiveness of weather derivatives as a risk management tool to mitigate maize yield volatility in South Africa. A quantitative research approach was employed, utilising Ordinary Least Squares (OLS) regression models to analyse the relationship between rainfall patterns and maize yields from 2000 to 2024. The study assessed historical rainfall data and maize yields in three key maize-producing regions: Bothaville, Harrismith, and Hoopstad. The study determined that rainfall variability influences maize production, although the impact differs by location. The effectiveness of weather derivatives, specifically rainfall options, was examined as a hedging strategy for farmers against unpredictable weather patterns. The study outlined two primary strategies – long-call and long-put options, which can provide financial protection against excess or insufficient rainfall. Findings indicated that while weather derivatives could mitigate financial risks associated with adverse weather conditions, challenges such as basis risk and limited market availability in South Africa remain. Additionally, results suggested that integrating rainfall options could complement traditional risk management methods such as insurance, offering farmers a more flexible approach to managing climate-related uncertainties. The study results are relevant for policymakers, financial institutions, and agricultural producers seeking alternative risk management solutions. The implementation of weather derivatives can improve resilience in the agricultural sector, ensuring more predictable financial outcomes for maize farmers facing climate uncertainty

Keywords: climate change; risk management; hedging strategies; food security; agricultural finance; commodity markets

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INTRODUCTION

Agriculture is a crucial pillar of economic growth and food security in developing nations, including South Africa. The sector not only contributes to employment and GDP but also provides income for millions, particularly small-scale farmers. However, agricultural production is highly susceptible to climatic variability, which poses significant risks to yields and farmer incomes. Extreme weather events such as droughts and erratic rainfall patterns have intensified, increasing uncertainty in agricultural output. As maize is a staple food crop and one of the most extensively cultivated commodities in South Africa, its production is directly influenced by weather conditions. Given the unpredictability of climate patterns, there is a pressing need for effective risk management tools to mitigate production losses. One such financial instrument is weather derivatives, which can protect farmers from adverse weather conditions that impact crop yields. Despite their potential benefits, the adoption and effectiveness of weather derivatives in South Africa remain underexplored. The study aims to fill this gap by evaluating how weather derivatives can be used to manage maize yield risks in the South African agricultural market.

A. Caldwell and D. Esterhuizen (2024) investigated the effects of the El Niño phenomenon on Southern African agriculture, highlighting the severe drought conditions that disrupted food production. Their study emphasised the necessity of adaptive strategies such as financial instruments to mitigate weather-related risks. Several studies also explored the use of weather derivatives in agricultural markets. J.D. Necker (2023) analysed how weather derivatives could protect from climate-induced yield fluctuations, highlighting that these methods provide financial stability to farmers during extreme weather events. J. Ngango *et al.* (2022) assessed the role of weather-indexed insurance in sub-Saharan Africa and found that such instruments help to reduce income volatility for smallholder farmers, thereby promoting agricultural investment. Additionally, M.R. Benso (2023) compared weather derivatives to traditional insurance mechanisms and argued that derivatives offer a more flexible and efficient risk management approach, as they do not require on-site damage assessments.

Furthermore, G. Kutrolli (2021) explored different weather-related financial instruments, including temperature and rainfall derivatives, emphasising their potential applications in commodity markets. The study suggested that integration of weather derivatives into existing agricultural financial frameworks could enhance farmers' resilience to climatic shocks. S. Ramachandran *et al.* (2024) analysed the adoption challenges of weather derivatives in developing economies, noting that limited financial literacy and market accessibility hinder their widespread use. On the other spectrum, K.C. Machete *et al.* (2024) argued that increasing awareness and providing policy support could encourage greater adoption among South African farmers. Despite these insights, gaps remain in understanding the practical implementation of weather derivatives in South Africa's maize market. The limited ability of farmers to accurately forecast weather conditions and commodity yields poses a significant challenge in planning production and financial strategies. Additionally, there is insufficient information and tools available for developing effective hedging strategies against weather-induced production risks.

Therefore, the study aimed to analyse the effectiveness of weather derivatives as a risk management method to mitigate maize yield volatility in the South African agricultural market.

MATERIALS AND METHODS

In this section, the relationship between rainfall and maize yield was highlighted by statistical tests. Further analysis quantified the effects of rainfall and maize yield and determined how it affected the price of maize. Weather insurance was evaluated to determine whether it was suitable for farmers to effectively hedge against adverse weather events. Weather derivatives were examined by proposing two different strategies for rainfall options: long call, and long put, and tested their effectiveness as a hedging method for farmers. This study used a quantitative design where secondary data were used. Secondary data refers to the use of data/information gathered or created by other institutions or researchers. OLS models were used to determine the correlation between rainfall and maize yields, proposing hedging strategies for farmers based on hypothetical scenarios.

The first step in the empirical portion of this study involved gathering data from multiple sources, including Grain SA, the South African Weather Service, and the Johannesburg Stock Exchange (JSE). The historical data collection was subject to encompass rainfall, input costs, spot prices for maize, and yields for white maize farmed in the North-Western Free State from 2000 to 2024. The South African Weather Service (SAWS, 2024) provided historical rainfall records, Grain SA provided historical yields, and the JSE provided historical spot prices for maize (JSE, 2024). Grain SA also supplied historical input costs (Grain SA, 2024). The secondary data gathered were processed annually, to ensure stability in the models. OLS models were used to determine the relationship between rainfall and maize yield while considering other variables, that provided a complete picture of factors affecting maize yield. Three Ordinary Least Squares (OLS) models were estimated for three different regions in the North-Western Free State. These OLS models were used to indicate the relationship between the yields and costs involved that guide farmers in making informed decisions to hedge their crops. The equation below was the OLS model for Bothaville.

$$Y=\beta 0+\beta 1X1+\beta 2X2+\ \beta 3X3+\beta 4X4+\beta 5X5+\epsilon, \quad (1)$$

where Y – dependent variable, in this model it was Bothaville Yield; X – independent variables; 0 – intercept (the value of Y when all X's = 0); $\beta 1$ – slope for Bothaville rainfall; $\beta 2$ – slope for Spot prices; $\beta 3$ – slope for Total Capital cost; $\beta 4$ – slope for Total cost per hectare; $\beta 5$ – slope for Cost per ton.
The equation below was the OLS model for Harrismith.

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$$\mathrm{Y}=\beta 0+\beta 1X1+\beta 2X2+\beta 3X3+\beta 4X4+\beta 5X5+\epsilon, \quad (2)$$

where Y – dependent variable, in this model it was Harrismith Yield; X – independent variable; 0 – intercept (the value of Y when all X's = 0); $\beta 1$ – slope for Harrismith rainfall; $\beta 2$ – slope for Spot prices; $\beta 3$ – slope for Total Capital cost; $\beta 4$ – slope for Total cost per hectare; $\beta 5$ – slope for Cost per ton.

The equation below was the OLS model for Hoopstad.

$$\mathrm{Y}=\beta 0+\beta 1X1+\beta 2X2+\beta 3X3+\beta 4X4+\beta 5X5+\epsilon, \quad (3)$$

where Y – dependent variable, in this model it was Hoopstad Yield; X – independent variable; 0 – intercept (the value of Y when all X's = 0); $\beta 1$ – slope for Hoopstad rainfall; $\beta 2$ – slope for Spot prices; $\beta 3$ – slope for Total Capital cost; $\beta 4$ – slope for Total cost per hectare; $\beta 5$ – slope for Cost per ton.

RESULTS AND DISCUSSION

This section illustrates and describes the descriptive statistics of the data used throughout the study. Descriptive statistics determined the used collected data. To provide an overview of the data used, the following descriptive statistics are analysed and discussed with the mean, median, maximum, minimum and standard deviations of all variables (Bothaville rainfall, Harrismith rainfall, Hoopstad rainfall, Bothaville yield, Harrismith yield, Hoopstad yield, Total cost, Total capital cost, Cost per ton and spot prices). Table 1 shows the descriptive statistics of all variables for the period 2000 to 2024.

***Table 1**. Descriptive statistics*

	Bothaville rainfall	Harrismith rainfall	Hoopstad rainfall	Bothaville yield ton/ha	Harrismith yield ton/ha	Hoopstad yield ton/ha	Total cost pe/ha	Total capital cost	Cost/ton	Spotprices
Mean	36.4354	44.1847	25.9847	4.5550	4.4721	4.9658	6,721.7988	770.1029	16261.2971	2213.7515
Median	33.8833	45.5750	24.7500	4.7700	4.6350	5.0850	6,710.7350	831.6400	1,204.7080	2,003.4418
Maximum	70.6000	78.1667	47.5000	6.3000	7.2300	6.9800	12,000.2100	1,075.4000	2,467.0208	4,446.6083
Minimum	0.0000	9.1200	3.7000	2.0800	2.7700	2.7300	2,206.8500	481.4500	582.2823	693.6215
Std. Dev.	19.1392	15.6521	12.1013	1.0857	1.2299	1.1125	3,003.6583	204.5236	508.1064	1,042.5540
Skewness	0.2087	-0.0561	-0.0794	-0.4425	0.3759	-0.2239	0.0493	-0.1406	0.5203	0.7476
Kurtosis	2.1255	3.0470	2.1247	2.4681	2.3881	2.2893	1.8096	1.5553	2.4364	2.7696
Jarque-Bera	0.9389	0.0148	0.7914	1.0663	0.9397	0.7056	1.4267	2.1661	1.4005	2.2888
Probability	0.6254	0.9926	0.6732	0.5868	0.6251	0.7027	0.4900	0.3386	0.4965	0.3184
Observations	24	24	24	24	24	24	24	24	24	24

***Source:** compiled by the authors*

Table 1 indicated that Bothaville has a mean of 36.44 mm of rain during the period 2000 until 2024, with a minimum (min) rainfall of 0 and a maximum (max) of 70.60 mm, and Bothaville has a high standard deviation (std dev) of 19.14. The standard deviation indicated a significant volatility in the weather patterns in Bothaville. Harrismith has a higher mean than Bothaville with 44.18 mm, a minimum of 9.12 mm, and a maximum of 78.17 mm. Harrismith's rainfall during the period 2000 to 2024 was less volatile than Bothaville, with a std dev of 15.65. Hoopstad received a mean rainfall value of 25.98 mm during the period 2009-2024 with a minimum of 3.7 mm and a maximum of 47.50 mm. The std dev for Hoopstad is 12.10 indicating less volatility in weather over the years. Possible reasons for volatility may be climate change due to the season of drought in all free states. Harrismith received the most rainfall, and Hoopstad the least rainfall on average.

Data represent the yield in Bothaville, Harrismith, and Hoopstad in tons per hectare (tt/haha). Bothaville has an average of 4.56 t/ha with a min value of 2.08 t/ha and a max value of 6.30 t/ha with a standard deviation of 1.09 indicating a moderate level of volatility. Harrismith has a lower mean yield compared to Bothaville with a mean of 4.47 t/ha and a min of 2.77 t/ha and a max of 7.23 t/ha, although the yield range is higher than Bothaville, the std dev of Harrismith is higher than 1.23, indicating higher volatility in yields over the period of 2000 until 2024. Hoopstad has the highest mean yield of 4.97 t/ha with a minimum value of 2.73 t/ha and a maximum value of 6.98 t/ha. The std dev of Hoopstad is 1.11, which indicates lower volatility compared to Harrismith and higher volatility compared to Bothaville.

In this Section, the total cost per hectare (ZAR/ha), total capital cost (ZAR), and the cost per ton (ZAR/t) are presented. The mean of the total cost per hectare is 6,721.80 ZAR/ha with a min value of 2,206.85 ZAR/ha and max value of 12,000.21 ZAR/ha and has a high volatility shown by the std dev of 3003.66. The total capital cost has a mean of 770.10 ZAR with a min of 481.45 ZAR and a max of 1,075.40 ZAR. The std dev of the total capital cost is 204.52, which indicates the medium levels of volatility experienced during the period 2000 to 2024. The cost per ton has a mean value of 1,261.30 ZAR with a min of 582.28 ZAR and a max of 2,467.02 ZAR, with a std dev of 508.11, which indicates high volatility over the period. The high volatility in cost per ton is attributable to the COVID-19 pandemic, which affected the entire economy and disrupted the supply and demand for agricultural commodities. The mean of the spot price has a value of 2,213.75 ZAR with a min of 693.62 ZAR and a max of 4,446.61 ZAR, with a std dev of 1,042.55, indicating that there was high volatility on the stock exchange for 2000 until 2024.

Most variables have skewness values close to zero, indicating a relatively symmetrical distribution. However, the price per ton and the price at the point of sale show positive skewness, suggesting a longer tail on the right side, and all variables with negative skewness indicate that it has a longer tail on the left side. Kurtosis values close to 3 indicate a normal distribution. Most variables have kurtosis values ranging around 2-3, suggesting a distribution close to normal. The Jarque Bera test for all variables indicates that the probabilities for all variables are higher than 0.05, indicating that the data do not deviate significantly from a normal distribution.

This section analysed the relationship between rainfall and maize yield. Rainfall is measured in millimetres (mm) and yields in tons per hectare. The correlation between rainfall and maize yields will be investigated for the three areas: Bothaville, Harrismith, and Hoopstad. Figure 1 illustrates how rainfall and maize yields changed from 2000 to 2024. Figure 1 illustrates that the rainfall has experienced great rainfall during the periods of 2003/04, 2005/06, and 2006/07, with the highest amount of rainfall over this period being for Harrismith, however, Harrismith experienced a downward trend in terms of rainfall in millimetres, which implies that over the sample period of 2000 to 2024 each year the amount of rainfall recorded is diminishing. Bothaville had a significant increase in rainfall from the 2008/09 season to 2011/12 and again in 2018/19 until 2022/23. Hoopstad had increased rainfall over seasons 2007/08 to 2011/12, then again in 2012/13 to 2014/15, again from 2015/16 until 2016/17, and in 2022/23 until 2023/24. Hoopstad receives on average less rainfall than Harrismith and Bothaville. The yields of all areas remain much more stable than the rainfall; this can also be determined by excessive rainfall during certain stages of the season, it does not result in higher yields. This implies that white maize will only need a certain amount of rainfall to a certain point where the excess rain will not cause the yield to increase, and a lot of excess rain can cause yield losses. This study is different from another study where J.D. Necker (2023) used three locations, namely: Bultfontein, Wesselsbron, and Hoopstad, whereas this study focused on Bothaville, Harrismith, and Hoopstad. Thus, in terms of location, only Hoopstad was used in both studies, the sample period is also different as this study used 2000 until 2024 whereas J.D. Necker (2023) used 2000 until 2020.

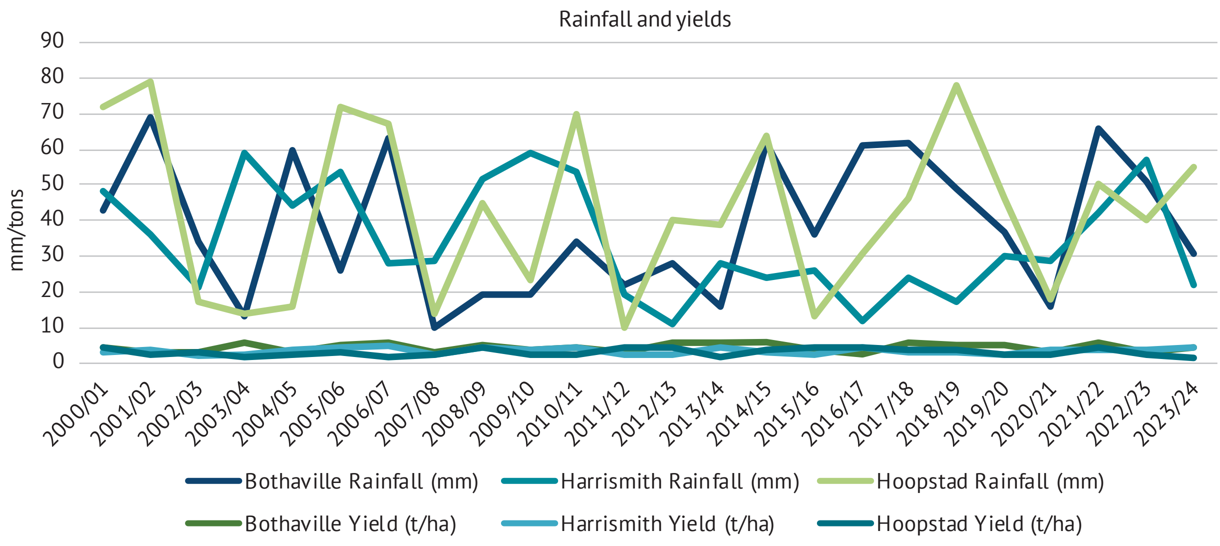

***Figure 1**. Rainfall and maize productions*

***Source:** compiled by authors*

Figure 2 shows a positive correlation between rainfall (mm) and yields (t/ha) for Bothaville. Figure 2 illustrates that rain will positively affect the yield in Bothaville; as rainfall increases, the yield will also increase, but only to an extent because extreme rainfall can destroy the harvest.

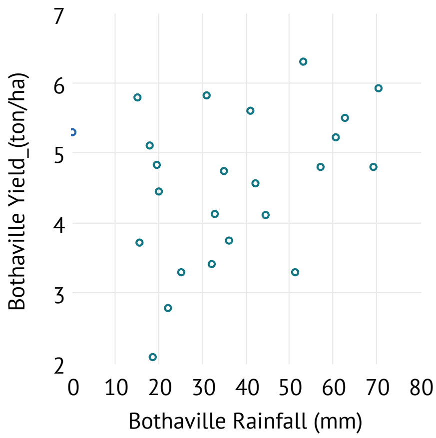

***Figure 2**. Bothaville correlation*
***Source:** compiled by authors*

Figure 3 shows a negative correlation between rainfall (mm) and yields (t/ha) for Harrismith. Figure 3 illustrates that rain will negatively affect yield in Harrismith; as rainfall increases, yield will decrease.

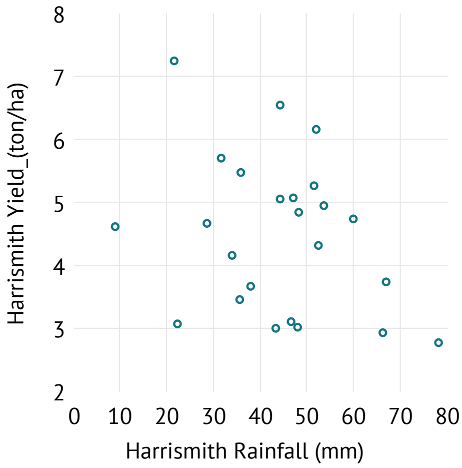

***Figure 3**. Harrismith correlation*
***Source:** compiled by authors*

Figure 4 demonstrated a positive correlation between rainfall (mm) and yields (t/ha) for Hoopstad. Figure 4 illustrates that rain will positively affect the yield in Hoopstad as rainfall increases, the yield will also increase, but only to an extent as extreme rainfall can destroy the harvest.

The previous study by J.D. Necker (2023) also graphically illustrated the correlation between rainfall and maize yields, and the results are similar in that this study also illustrated the positive correlation between rainfall and maize yields. In Table 2 the (OLS) model was implemented where the yield per ton per hectare is a dependent variable to determine how independent variables affect the yield. Interception (C) is statistically significant, which means that if all other variables are zero, the yield per hectare is 4.27 tons. Rainfall in Bothaville has a positive and small influence on yields, therefore rainfall in this model has insignificant impact on yields. This finding related to a study by T.A. Marton *et al.* (2020) which also found that rainfall has an impact on crop yield.

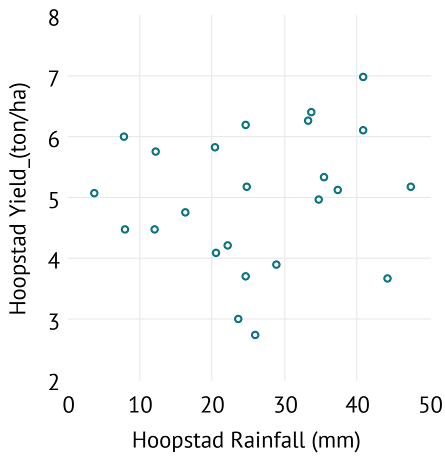

***Figure 4**. Hoopstad correlation*
***Source:** compiled by authors*

Although in Figure 2 there is a positive relationship between rainfall and yield, additional variables are needed to ensure significant effects. Spot prices have a negative impact on yields but are not significant. Total capital costs have a positive, but statistically insignificant, impact on yields. This indicates that changes in capital cost do not significantly affect yield. The total cost of each hectare has a positive and statistically significant impact on yields. This shows that higher costs per hectare are associated with higher yields. The cost per ton has a negative and statistically significant effect on the yield. This indicates that higher per-tonne costs are associated with lower yields. The squared R of this 0.4069 model indicates that this model explains 40.69% of the yield variations. Adjusted R squared of 0.2422 shows that, after adjustment, the model explained only 24.22% of the yield variation. The probability (F-statistic) of 0.0716 indicates that the overall model is statistically significant at 10%, indicating that the variables together explain the variability of the yield significantly. However, some variables, such as the total cost per hectare and the cost per ton, are statistically important, and the overall model is not suitable to effectively determine yields and additional variables, or different models are needed.

Table 2. *Bothaville OLS model*

(a)		(b)	Bothaville		
(c)	Variables	(d)	Coefficient	(e)	Probability
(f)	C	(g)	4.270846	(h)	0.000089
(i)	BOTHAVILLE_RAINFALL_MM_	(j)	0.004826	(k)	0.695158
(l)	SPOTPRICES	(m)	-0.000375	(n)	0.295484
(o)	TOTAL_CAPITAL_COST	(p)	0.000556	(q)	0.778585
(r)	TOTAL_COST__PE_HA_	(s)	0.000453	(t)	0.022964
(u)	COST__TON_	(v)	-0.002010	(w)	0.014025
(x)		(y)		(z)	
(aa)	R-squared	(bb)	0.406903		
(cc)	Adjusted R-squared	(dd)	0.242154		
(ee)	Prob(F-stat)	(ff)	0.071653		

Source: *compiled by the authors*

In Table 3 of the OLS model, the dependent variable is the Harrismith yield ton per hectare, that determined how the independent variables affect the yield. The intercept is statistically significant when all other independent variables are zero and have a value of 3.70 tons per hectare. Harrismith rainfall has a negative value and is also not significant and thus does not substantially impact the yield in the model. This finding contradicts the results of T.A. Marton *et al* (2020) which found that rainfall has little impact on yield. Spot prices have a negative, but not statistically significant, effect on yield. This indicates that changes in spot prices do not significantly affect yield. The total capital cost has a positive and statistically significant effect on the yield. This suggests that higher capital costs are associated with higher yields. The total cost per hectare has a positive but not statistically significant effect on yield. This indicates that higher costs per hectare do not significantly affect yield. The cost per ton has a negative and statistically significant effect on yield. This suggests that higher costs per ton are associated with lower yields. This model has an R-squared of 0.5188 which indicates that 51.88% of the variation in yield is explained by this model. After adjustments in variables, the adjusted R-squared has a coefficient of 0.3851 which indicates that 38.51% of the variation in yield is explained by this model. The Prob(F-stat) is 0.0146 which indicates that the model is statistically significant at a 5% level and that the model together explains the variation in the yield.

Table 3. *Harrismith OLS model*

(a)		(hh)	Harrismith		
(ii)	Variables	(jj)	Coefficient	(kk)	Probability
(ll)	C	(mm)	3.69920694	(nn)	0.0318
(oo)	HARRISMITH_RAINFALL_MM	(pp)	-0.02248777	(qq)	0.2842
(rr)	SPOTPRICES	(ss)	-0.00031579	(tt)	0.3803
(uu)	TOTAL_CAPITAL_COST	(vv)	0.00571212	(ww)	0.0067
(xx)	TOTAL_COST__PE_HA_	(yy)	0.0001005	(zz)	0.6283
(aaa)	COST__TON_	(bbb)	-0.0020684	(ccc)	0.0104
(ddd)		(eee)		(fff)	
(ggg)	R-squared	(hhh)	0.518811		
(iii)	Adjusted R-squared	(jjj)	0.385148		
(kkk)	Prob(F-stat)	(lll)	0.014595		

Source: *compiled by the authors*

In this Table 4 of the OLS model, the dependent variable is the Hoopstad yield ton per hectare, to determine how the independent variables affect the yield. The intercept is statistically significant at all levels with a coefficient of 3.95 tons per hectare when all other variables are zero. Hoopstad rainfall has a negative but insignificant effect on yield, which implies that the variation in rainfall does not significantly affect yield in this model. This finding contradicts the results of T.A. Marton *et al* (2020) which found that rainfall has little impact on yield. Spot prices have a negative, but statistically significant, impact on yields. This indicates that changes in spot prices do not have a significant impact on yields. The total capital cost has a positive and insignificant effect on the yield; therefore, variations in total capital cost do not impact the yield. Total cost per hectare has a positive and statistically significant effect on yield. This indicates that higher costs per hectare are associated with higher yields. The cost per ton has a negative and statistically significant effect on yield. This suggests that higher costs per ton are associated with lower yields. This model has an R-squared of 0.7995 which indicates that 79.95% of the variation in yield is explained by this model. The adjusted R-square of 0.7438 indicates that 74.38% of the variation in yield is explained by this model after adjusting the variables. This is a notable pattern, which the adjusted R-squared and R-squared are indicating. The Prob (F-stat) is 0.00001; thus, the model is statistically significant at all levels, and it does significantly determine the variation in yield.

***Table 4**. Hoopstad OLS model*

(mmm)		(nnn)	Hoopstad		
(ooo)	Variables	(ppp)	Coefficient	(qqq)	Probability
(rrr)	C	(sss)	3.94543737	(ttt)	0.0000
(uuu)	HOOPSTAD_RAINFALL_MM	(vvv)	-0.0014734	(www)	0.9104
(xxx)	SPOTPRICES	(yyy)	-6.383E-05	(zzz)	0.7603
(aaaa)	TOTAL_CAPITAL_COST	(bbbb)	0.00116963	(cccc)	0.3923
(dddd)	TOTAL_COST__PE_HA	(eeee)	0.00054684	(ffff)	0.0001
(gggg)	COST___TON_	(hhhh)	-0.002677	(iiii)	0.0000
(jjjj)		(kkkk)		(llll)	
(mmmm)	R-squared	(nnnn)	0.799497		
(oooo)	Adjusted R-squared	(pppp)	0.743802		
(qqqq)	Prob(F-stat)	(rrrr)	0.000010		

***Source:** compiled by the authors*

The study highlighted the importance of agriculture in South Africa by analysing food security, stability, and contribution to the GDP. The various risks associated with agriculture were highlighted, while the yield risk, specifically in the maize commodity, was defined as primary. Illustration of how yield risk varied in climate change. Weather derivatives are determined by their use as protection against weather conditions, rather than weather insurance as the only mitigation of these risks. The differences between weather insurance and weather derivatives were analysed in detail to highlight the importance of weather derivatives as a risk management method to mitigate yield risk. Rainfall options will be outlined to determine if it is financially feasible for South African farmers, as well as the ability to manage yield risk.

The agricultural sector was deemed to be complex, and a market filled with volatility (Mbatha, 2020). The agricultural industry has changed in many ways, drought and declining rainfall impacted the agricultural sector significantly causing farming profitability to drop; keeping up with the latest technology in a constantly changing sector, has costly implications for crop farmers, as they need to employ new farming techniques and improved products for them to continue producing and compete in the competitive agricultural sector (Blaker, 2021). The agriculture sector in South Africa is responsible for producing a variety of products: wine, fruits, vegetables, grains, oils, cereals, and many others. Production of all different crop types is exposed to different factors that influence production and the environment (Necker, 2023). Agriculture is particularly important in contributing to economic growth in various countries and economies around the world (World Bank, 2024). Agriculture globally contributes 4% to GDP, while in developing countries it can be more than 25% (World Bank, 2024).

According to J.D. Necker (2023), it is necessary prioritise a well-defined and healthy agricultural sector to contribute to GDP, promise food security and create employment opportunities in the agricultural sector of South Africa. During the COVID-19 pandemic, the South African economy suffered severely; however, out of all sectors, the agricultural sector contributed the most to the economy in terms of GDP growth in the last quarter of 2021 (Stats SA, 2022). This demonstrated that agriculture is crucial for a strong economy and is a key driver of economic growth, although there are many risks in the agricultural sector. Agriculture, forestry and fishing grew by 13.5% in Q1 of 2024 and contributed 0.3% to GDP growth, while the whole economy with all sectors considered indicates that in Q1 of 2024, the GDP declined by 0.1%, this highlights the significant role that agriculture plays in the economy, due to being the highest growing sector in South Africa according to statistics from Stats SA in the first quarter of 2024 (Stats SA, 2024).

Production risks are common in the agricultural sector; farmers must produce crops to comply with regulations to ensure that the commodity is safe and healthy to consume. However, it does not stop pests as they can also destroy a harvest, for instance, many birds eat the crops, and insects kill the crops (ERS, 2024). Financial risks in agriculture include the need for more funds/capital to continue their operations and are forced to borrow money, thus to repay their debt. To repay their debt, farmers need to ensure sufficient profit with the crop yields. The study by A. Polevoy *et al.* (2021) highlighted the significant impact of climate change on maize productivity in the Western Forest-Steppe of Ukraine, emphasising the increasing variability in temperature, precipitation, and extreme weather events. Their findings align with the present research, reinforcing the necessity of adapting agricultural practices to mitigate climate-related risks in maize cultivation.

The rapid growth in food demand relative to global warming transfers numerous pressures on farmers to adapt to farming practices that will result in less crop loss due to climate change, specifically drought and extreme heat conditions (Hall & Leng, 2019). A significant constraint to crop yield is drought as an adverse weather condition, since drought influences crop satisfaction to grow efficiently to provide optimal harvest, drought also has a negative effect on farmers, as irrigation is now necessary to provide the optimal water levels that will influence profit levels and the financial space that farmers are in (Hall & Leng, 2019). Variations in weather conditions and temperature changes are called climate changes. Production, together with prices in agriculture, is exposed to more risk due to increased climate change (Elum *et al.*, 2018).

The term "weather sensitivity" refers to the degree to which weather factors, such as temperature, sunshine, rainfall, frost, snowfall, wind, etc., affect sales, production, or expenses. A sector is considered weather-sensitive if weather variations affect its volatility of production. A wide range of people whose livelihoods depend on land and resources are negatively impacted by climate change Agriculture in South Africa faces a greater risk of climate and yield due to the large percentage of agriculture that depends on rainfall/irrigation (Nhamo *et al.*, 2019). The main source of income in South Africa is agriculture formally and informally. A study outlined climate change and how it affects agricultural production; analysed an increase in temperature and a decrease in rainfall and the effect of variability in weather conditions on the production of agricultural commodities. The study concluded that changes in temperature and rainfall have a negative impact on production (Abbas & Mayo, 2021; Moore, 2021). According to S. Abbas and Z.A. Mayo (2021), low levels of rainfall causes in low yields, thus climate change negatively affects the agricultural sector not only in terms of financial challenges but in terms of production yields. Weather insurance or weather derivatives are a solution to the climate change problem, which directly impacts agriculture and is a risk management tool farmers can use to hedge against yield risk/climate change.

Due to financial losses that increase from climate change and climate-related risks, weather derivatives were created and developed in 1999 in the United States to help mitigate losses incurred by adverse weather conditions. The first weather derivatives contract was initiated in 1999. Derivative products, such as options and swaps, can be traded or sold to the seller to act as weather insurance, as highlighted by J. Li *et al.* (2024). Weather derivatives can be bought and sold before maturity to ensure the profit. The seller of a weather derivative contract agrees to pay a certain amount to the buyer in exchange for a premium if a weather event occurs or the buyer suffers a financial loss related to the weather before the end of the contract. If the contract expires and damages are not caused, the seller's profit is the premium or derivative price at the time of its creation, according to CDI (2021). The weather indices determine the derivative contract; the index of the weather derivatives acts as the underlying asset because, unlike other derivative contracts, weather derivatives do not have a spot market.

Weather insurance is more commonly used as a risk management method as it can be used to account for adverse weather events by covering a low probability of occurrence but can result in substantial losses, as explained by J. Tack and J. Yu (2021). Weather derivatives, in contrast to insurance, are suitable for high-probability occurrences that may result from weather conditions or climate change. The researchers emphasise that weather derivatives offer protection against high-probability events such as droughts and extreme heat or the opposite, with excessive rain or extreme cold. What distinguishes weather derivatives from weather insurance is the lower costs involved. Because individual yield changes are usually not related to the relevant weather variables, the use of weather derivatives still involves a large amount of risk for producers, as the risk remains with producers.

Weather derivatives also have a risk that might occur due to inaccuracies in measuring the weather. A well-known risk associated with weather derivatives is the basis risk. G. Kutrolli (2021) described basis risk as a case where the derivative price does not show the same movements as that of the underlying instrument, meaning there is no perfect correlation. Basis risk would be experienced in weather derivative contracts when there are different weather conditions or climate change at various weather measurement plants within the borders of the country. While basis risk cannot be eliminated due to inherent inaccuracies in measurement, farmers must acknowledge and accept this risk when using weather derivatives to hedge against maize yield. According to J. Li *et al.* (2003), the significant relationship between production variables and weather factors is an important motivation for participating in weather derivative contracts.

There are numerous ways in which rainfall options can be made. The most popular options that benefit farmers consist of "locking" at a certain amount of rainfall: the long call option, the long-put option, and a combination of the long call and put options, as described by G. Kutrolli (2021). A long-call option can be used to protect against adverse rainfall. For example, farmers may buy 5-month call options in case of excessive rainfall and flooding. If the average rainfall in the area is, for example, 425 mm over a certain period, farmers will protect themselves from excess rainfall. Farmers can use a long-put option if there is a need for a certain amount of rainfall. For instance, if they need rain between March and May, the farmer can buy a 3-month put option and be protected if less rain falls during that specific period. When the farmer needs rain during a specific period from January to June, a combination of put and call options can be employed. Farmers are then protected against excessive or insufficient rain during this period. With a rainfall index, the rainfall choice would have a strike rate determined by historical rainfall data for the location. J.D. Necker (2023) stated that the strike point would be established by the amount of rain, measured in millimetres, during a given period. For instance, a 6-month call option covering the period from January to June will have a 350 mm strike rate if the area's average rainfall during that time is 350 mm. The actual amount of rain that falls over that period will decide the option's payout, which is predetermined per millimetre. Therefore, weather derivatives will be beneficial in mitigating exposures to weather fluctuations.

Agriculture is central in South Africa due to promotion of economic growth in terms of GDP, alleviating poverty through employment, and ensuring food security nationwide, as noted by J.D. Necker (2024). South African agriculture sector, more specifically commercial agriculture, is the driving force in the industry with the highest growth rate, according to Stats SA (2024). Maize is not only a staple food but also the largest contributor to GDP in the farming industry. Climate risk is the main reason for the extreme level of demand for products that protect against weather conditions negatively affecting farmers. Thus, as J. Li *et al*. (2024) noted, weather derivatives are a solution against climate risks or adverse weather conditions. Similarly to any other risk management method, the most important objective of weather derivative implementations is to mitigate the volatility of income and expenses brought on by non-catastrophic weather uncertainty, as J.D. Necker (2023) states. Rainfall options will be applicable for farmers to use to protect them against yield risk, enabling adaptation and and survival in a rapidly changing environment, providing essential protection against climate change.

The study determined that rainfall and maize yield have a positive relationship in general, and the three OLS models that were done indicate that the model does explain the variables in yield. However, as Santam (2024) notes, there are several ways of insurance drought and extreme rainfall. This can be done in various ways, such as weather insurance and weather derivatives. In South Africa, Santam offers insurance against droughts, with the exception that it cannot be irrigated or damaged from plague and pests, hail, wind, or even frost. Weather insurance is commonly used to mitigate yield risk against adverse weather events with a low probability of occurring. However, as G. Kutrolli (2021) highlighted, the drawback of weather insurance is that in South Africa, there are no crop insurance offers to protect farmers against rain specifically for maize. Rainfall options are used to hedge farmers for the difference in yield lost due to excess shortage or rainfall, whereas weather insurance covers the entire harvest.

White maize is a highly liquid agricultural commodity that is traded, which causes prices to vary. G. Kutrolli (2021) stated that weather derivatives offer two main types of hedging strategies for farmers to use: futures contracts and rainfall options. Rainfall options are more relevant than futures as, with options, farmers have the right but not the obligation to act, whereas, with futures, they need to hold the contract and adhere to the conditions. Using rainfall options, farmers will benefit more compared to futures contracts due to the fact that with options, they are only subject to a loss in the premium paid. In summary, as G. Kutrolli (2021) stated, rainfall options offer greater flexibility, fewer risks, and potentially lower costs, making them more attractive for farmers who want to hedge against certain weather-related risks without the requirement of fulfilling a contract under unfavourable conditions.

The farmer can use a long call option depicted in Figure 5 to be protected against adverse rainfall, for example, farmers can buy 6-month call options at R2350, which may be a threat of excessive rainfall and flooding. If the average rainfall in the area is, for example, 425 mm over a certain period, farmers will be protected from excess rainfall. The buyer of the option has the right but not the obligation to exercise. Therefore, if the rainfall is higher than when the option was bought, the farmers will profit. And when the farmer decides to exercise the right, a significant profit will be made. When the rainfall is less, the farmer or buyer of the option will only lose the paid premium.

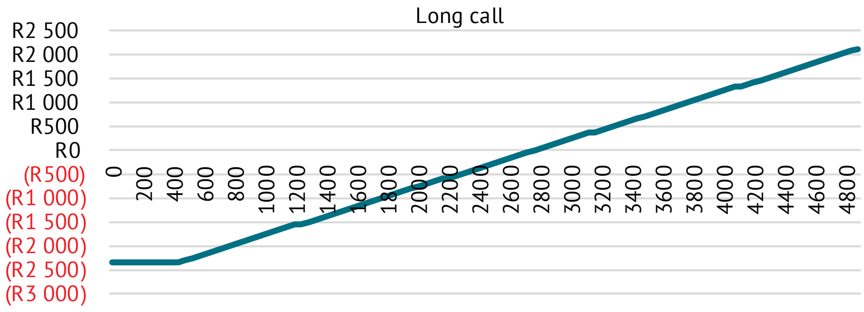

Figure 5. *Long-call option example*

Source: *compiled by authors*

Farmers can use a long-put option depicted in Figure 6 to be protected from rainwater shortage; for instance, if they need rain between March and May, the farmer can buy a 3-month put option and then be protected if the farmer receives less rain during the specific period.

A long-put option will provide farmers with the benefit of being able to receive less rainfall than when the option was purchased. If the rainfall levels were exceeded, only the premium will be lost otherwise with less rainfall, in the case of a drought, significant profits/benefits will be provided.

***Figure 6**. Long put option example*

***Source:** compiled by authors*

The key difference between this study and J.D. Necker (2023) is that it explores hedging strategies less thoroughly, does not price rainfall options, and instead focuses on hypothetical scenarios. The main objective of the study was to determine whether weather derivatives are effective as a risk management method to mitigate against volatility of maize yields in the South African agricultural market. Weather derivatives cover low-risk and high-probability events, whereas insurance covers high-risk and low-probability events. The rain option as the weather derivative gives farmers the option to make a profit with the unpredictability of rainfall. With the input cost increasing due to inflation and out-of-control as well as weather events, rainfall options are a tool that offers a hedge against yield risk at a lower cost. With a long-call option or long-put option, farmers can now hedge yield risk in times of drought or less-than-needed rainfall and times when there is excess rainfall damaging the harvest. Thus, rainfall options are a great strategy farmers can use to hedge against yield risk; however, in South Africa, rainfall options are not yet traded on the exchange. Therefore, South Africa's agricultural market, will not be able to use rainfall options as it is yet, but in the near future, it will be possible if weather derivatives become more popular and available.

CONCLUSIONS

The study analysed the effectiveness of weather derivatives as a risk management method for mitigating maize yield risk in South African agricultural markets. The study conducted a literature review on agricultural importance, climate change and weather derivatives as a more beneficial alternative to weather insurance together with the methodology section to illustrate the relationships between rainfall and maize yield. The methodology section used OLS models to estimate the effects of input costs and rainfall on maize yields for the respective location samples for the period of 2000 to 2024. The study highlighted that higher costs per hectare are associated with higher yields, and that rainfall does impact yield, but it is not always statistically significant. The problem that farmers face is the impossibility of accurate measurement of the rainfall, as weather stations capture the data for that location, but it is not accurate for farmers close to the area to assume they have the same since rainfall varies significantly. Therefore, farmers may need to measure their rainfall to effectively be able to estimate their yields and rainfall with highly accurate data.

The study demonstrated that it can be financially feasible for farmers to use weather derivatives as a risk management tool to mitigate the risk of maize yield. For future research opportunities, a larger location sample can be used to gather more data to determine if the results are similar to a larger study area covered. Pricing rainfall options accurately is needed to be able to provide farmers with effective strategies, and the period can be increased to incorporate more economic and geopolitical events which will affect the price. Further study should expand geographical coverage beyond the studied regions to assess broader applicability, incorporate additional variables such as temperature and soil moisture for improved model accuracy, and explore the pricing and market feasibility of rainfall derivatives in South Africa. Comparative analysis with traditional insurance models could determine the most effective risk management approach. Extending the study period to capture long-term economic and climate trends, along with simulation-based risk assessments, would provide deeper insights into maize yield volatility and hedging strategies.

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CONFLICT OF INTEREST

None.

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Погодні деривативи та ризик врожайності кукурудзи на сільськогосподарському ринку Південної Африки

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Анотація. Кліматична мінливість суттєво впливає на продуктивність сільського господарства, що зумовлює необхідність у застосуванні інструментів управління ризиками для стабілізації врожаїв та фінансових результатів. Метою цього дослідження було оцінити ефективність погодних деривативів як інструменту управління ризиками для зменшення волатильності врожайності кукурудзи в Південній Африці. Було застосовано кількісний підхід до дослідження із використанням моделей регресії найменших квадратів (OLS) для аналізу взаємозв'язку між кількістю опадів та врожайністю кукурудзи у 2000-2024 роках. Аналіз охопив історичні дані про опади та врожайність у трьох ключових регіонах вирощування кукурудзи: Ботавілл, Гаррісміт та Хупстад. Встановлено, що варіативність опадів впливає на виробництво кукурудзи, хоча інтенсивність впливу варіюється залежно від локації. Було розглянуто ефективність погодних деривативів, зокрема опціонів на дощі, як стратегії хеджування для фермерів, які стикаються з непередбачуваними погодними умовами. У дослідженні описано дві основні стратегії — опціони типу «лонг-кол» та «лонг-пут», які забезпечують фінансовий захист у разі надлишкових або недостатніх опадів. Результати засвідчили, що погодні деривативи можуть зменшити фінансові ризики, пов'язані з несприятливими погодними умовами, однак залишаються виклики, зокрема ризик невідповідності базових показників (basis risk) та обмежена доступність таких інструментів на ринку Південної Африки. Крім того, встановлено, що інтеграція опціонів на дощі може ефективно доповнити традиційні інструменти управління ризиками, зокрема аграрне страхування, надаючи фермерам більш гнучкий підхід до реагування на кліматичні ризики. Отримані результати становлять практичну цінність для органів державної влади, фінансових установ та сільськогосподарських виробників, які шукають альтернативні шляхи пом'якшення ризиків. Запровадження погодних деривативів здатне посилити стійкість аграрного сектору, забезпечуючи більш передбачувані фінансові результати для виробників кукурудзи в умовах кліматичної невизначеності

Ключові слова: зміна клімату; управління ризиками; стратегії хеджування; продовольча безпека; аграрне фінансування; товарні ринки