



Integrated Excel-Based Stochastic Model for Predicting Maize Crop Resilience under Climate Variability in Kenya

Abstract: Climate change is threatening agricultural systems in Sub-Saharan Africa due to unpredictable rainfall levels and increases in temperature, resulting in adverse effects on crop productivity and food security. This paper introduces a stochastic model for predicting crop resilience based on climate change in a shifting climate regime, specifically focusing on maize cultivation in Kenya. The analysis is based on a 30-year data set from 1995 to 2024 on annual rainfall levels, temperature changes, and maize yield. The stochastic modeling process includes the use of probabilistic tools like Monte Carlo simulations. Statistical measures, including yield variation, crop failure probability, and Crop Resilience Index (CRI), will be used to measure system stability under varying climates. Results show high inter-annual variability in precipitation, but a consistent rise in temperatures has led to highly variable levels of maize production. The results of simulation demonstrate that there is a moderately resilient nature of crops, with about 18% to 22% chances of a low yield in cases of unfavourable weather. This study concludes that rainfall variability plays the biggest role in affecting crop yields, whereas rising temperatures contribute to increased stress on the crops. Results shows that stochastic models based on Microsoft Excel can be used effectively as a low-cost decision support system for evaluating climate risks in resource-scarce regions.

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1. Introduction

Agriculture serves as the primary economic foundation for various Sub-Saharan African nations while providing essential employment opportunities and ensuring food security and driving growth in gross domestic product. The agricultural sector faces severe risk from climate changes especially the unpredictable patterns of rainfall and the rising temperatures that occur throughout the year. The rising climatic uncertainties that emerged during the last 50 years present major obstacles to both sustainable agricultural practices and the functioning of rural communities (Mpundu & Bopape, 2022).

The agricultural sector in Kenya makes up a major portion of the country economic activities while providing employment to a large segment of the population. Maize serves as an essential staple crop because it provides food and generates economic value for farmers. The rain-dependent nature of maize farming in Kenya makes it vulnerable to changes in both rainfall and temperature. The combination of frequent droughts and unpredictable rainfall



patterns and increasing temperatures has resulted in substantial yield variations which heighten the possibility of food shortages(Ngeno, 2024). The scientific study of crop yield prediction has depended on deterministic models which establish constant relationships between climatic conditions and crop production results. The models serve as baseline assessment tools, but they do not effectively measure the unpredictable nature of climatic conditions and their capacity to change. Agricultural scientists need to develop systems that use probabilistic methods to handle unpredictable factors while generating accurate agricultural yield predictions for different environmental scenarios.

The application of stochastic modeling through Monte Carlo simulation methods provides researchers with an effective method to study agricultural system uncertainty and system variability. Stochastic models create multiple potential outcomes through their treatment of probabilistic inputs, which allows researchers to evaluate climate change risks in a complete manner. The complex modeling tools need specific software and technical skills to operate, which prevents their use by people who live in developing countries. The study is Excel-based stochastic modeling system which predicts crop resilience through its application to changing weather patterns(He et al., 2023). The Microsoft Excel platform enables users to conduct probabilistic simulations because its user-friendly interface requires no advanced programming expertise. The model uses past climate data and crop yield data to create different scenarios which test the resilience of maize production systems.

The research investigates how climate variability affects maize yield in Kenya while creating a stochastic model which predicts crop resilience. The study will achieve its goals through four specific objectives which include:

- a) analyzing historical trends in rainfall and temperature,
- b) evaluating the relationship between climatic variables and maize yield,
- c) simulating yield variability using Monte Carlo techniques, and
- d) developing a Crop Resilience Index to quantify system stability under uncertain climatic conditions.

2. Literature Review

2.1 Climate Variability and Agriculture in Sub-Saharan Africa

Sub-Saharan African agriculture depends on rain because its agricultural systems use rain-fed water sources for farming. Numerous studies have reported that rainfall patterns and temperature increases lead to major decreases in crop yields throughout the entire region. Erratic rainfall patterns together with extended drought conditions and severe weather events have caused farmers to experience decreased crop production combined with uncertain agricultural results. Climate change projections indicate that existing challenges will become more severe which will result in increased food shortages and greater economic hardships(Omotoso et al., 2023).

2.2 Crop Resilience and Yield Stability

Crop resilience describes how agricultural systems can endure and modify to withstand climatic stresses while maintaining their productive capacity. The assessment of the system requires measurement through yield stability and extreme event resistance together with recovery ability after disturbance events. Research shows that multiple factors determine resilience, which includes climate changes and soil properties and crop varieties and farming methods. The distribution of rainfall directly affects yield stability in rain-fed agricultural systems which causes crops to become extremely susceptible to drought conditions(Yi & Jackson, 2021).



2.3 Climate Impacts on Maize Production in Kenya

The main crop which ensures food security for Kenya is maize because it serves as their main agricultural product. The studied research demonstrated that climatic conditions function as the primary factor which determines maize agricultural output in Kenya. The main factor which determines successful maize production depends on rainfall patterns because inadequate or unorganized rainfall distribution leads to significant crop losses. Rising temperatures create conditions which result in increased water loss from crops thus leading to reduced farm productivity. The research findings show that drought conditions result in severe decreases of maize output whereas sufficient rainfall periods lead to improved farming results.

2.4 Stochastic Modeling for Agricultural Systems Research

Stochastic modeling has become an effective method for investigating the unpredictable elements and changing patterns which exist in agricultural systems. Stochastic models use random elements together with probability distribution functions to create different potential outcomes. The Monte Carlo simulation method has become a popular tool for estimating agricultural risk factors that relate to climate change. The system generates multiple outcomes through its analysis of input distribution which allows researchers to assess various yield scenarios including the extreme case of total crop failure. The research proves that stochastic approaches create better climate-crop relationship models which produce real results when compared to traditional research methods(Dogouri et al., 2025).

2.5 Application of Excel-Based Models in Research

Researchers from different fields use Microsoft Excel as their primary modeling tool because of

its ability to provide accessible and flexible functions which users can operate with basic skills. Researchers in agricultural and environmental studies use Excel to perform data analysis work and create simulation models and build decision support systems. The built-in functions of the software, which include random number generation, and data tables enable users to perform Monte Carlo simulations without requiring them to learn advanced programming skills. The Excel-based models provide an ideal solution for developing regions because these areas lack access to specific software that requires expertise for operation.

2.6 Research Gap

The current research about climate variability and agricultural productivity lacks integrated user-friendly tools which combine stochastic modeling with existing Excel-based platforms. Existing research studies either examine specialized simulation environments or specific regional studies without creating solutions which practitioners can use with ease. The development of a comprehensive Crop Resilience Index through probabilistic methods remains underexplored in Sub-Saharan agriculture research.

3. Methodology

The research examines Kenya which is situated in Sub-Saharan Africa and depends on rain-fed agriculture that suffers from climate changes. Maize was selected as the representative crop due to its importance as a staple food and its strong dependence on rainfall patterns. The research investigates how climate variability affects maize yields while creating a stochastic model to measure crop resistance during unpredictable weather patterns(Dlamini et al., 2025).

The climate data used in this study were obtained from the NASA POWER database and the World Bank Climate Change Knowledge



Portal. Monthly climatic variables for Kenya covering the period 1995–2024 were downloaded from the NASA POWER database in CSV format. The variables extracted included corrected precipitation (PRECTOTCORR) and average air temperature at 2 m height (T2M). The dataset has a spatial resolution of $0.5^\circ \times 0.625^\circ$ and was accessed on 05 May 2026.

Crop yield data were obtained from FAOSTAT. Annual maize yield data for Kenya covering the period 1995–2024 were extracted from the FAOSTAT Crops and Livestock Products database. The dataset was downloaded on 06 May 2026 and expressed in kg/ha. These datasets were selected due to their reliability, global coverage, and extensive use in climate and agricultural research.(Kipkulei et al., 2024). The research framework uses statistical methods and stochastic methods to study how climate variables affect agricultural production. The researchers studied the central tendency and variability of rainfall, temperature, and yield data through descriptive statistical analysis. The researchers utilized mean and standard deviation and range measurements to assess the extent of climatic fluctuations which might impact agricultural productivity. The researchers conducted correlation analysis to study how rainfall and temperature and maize yield relate to each other to determine how climate factors affect crop growth(Waqas et al., 2024).

The researchers utilized Monte Carlo simulation through a stochastic modeling method to tackle problems stemming from unpredictable climate patterns. The researchers created their model through Microsoft Excel which provides users with straightforward access to probability-based simulations. The researchers used probability distributions to match historical rainfall and temperature data which they assumed to follow normal distribution patterns based on their actual

measurements. The built-in Excel functions generated random values for these variables which researchers used to calculate maize yields by establishing connections between climate factors and crop production. The Monte Carlo simulation executed 1000 iterations to produce multiple potential yield results which depended on different weather patterns. This method enabled researchers to create yield probability distributions which helped them find extreme scenarios while studying how agricultural production faced unpredictable outcomes. The simulation results provided insights into different yield levels which included low-yield events that serve as critical factors for assessing agricultural risk(Laub et al., 2025b).

A Crop Resilience Index (CRI) was developed to quantify the stability and adaptability of the maize production system under climate variability. The index assesses crop yield fluctuations together with the likelihood of crop failure and the system's capacity to bounce back from better times. A higher CRI indicates greater resilience, while a lower value reflects increased vulnerability to climatic stress. The researchers used scenario analysis to study how various climate conditions affect crop yield results. The researchers established three scenarios which included drought conditions and normal weather and high rainfall weather based on specific rainfall thresholds present in the dataset. The researchers studied how different climatic conditions affect maize yield throughout the research process(Sahoo et al., 2024).

The model validation process involved comparing simulated yield results with historical data through standard error metrics that included Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) measurements. The validation process confirmed that the model could accurately represent actual world variations which



demonstrated its research ability. The methodology establishes an Excel-based system that enables researchers to measure crop resilience under unpredictable climate conditions through comprehensive assessment methods (Hodson, 2022).

3.1 Mathematical Formulation of the Stochastic Model

To incorporate uncertainty in climatic variables, a stochastic simulation framework based on Monte Carlo analysis was implemented using Microsoft Excel. Historical rainfall and temperature datasets were used to generate probabilistic climate scenarios. The simulation process involved random sampling from statistical distributions fitted to observed climate variables.

The rainfall and temperature values were generated using the following normal distribution function:

$$X = \mu + Z\sigma$$

where:

- X = simulated climate variable
- μ = mean of historical observations
- σ = standard deviation
- Z = standard normal random variable generated using Excel functions

In Microsoft Excel, the stochastic variables were generated using:

=
NORM.INV(RAND(), Mean, Standard Deviation)

where *RAND()* generates a random probability value between 0 and 1.

The maize yield estimation model was developed using a simplified linear relationship between climatic variables and crop yield:

$$Y = a + b_1 R + b_2 T$$

where:

- Y = maize yield (t/ha)
- R = annual rainfall (mm)
- T = average temperature ($^{\circ}\text{C}$)
- a = intercept term
- b_1 = regression coefficients

The Crop Resilience Index (CRI) was calculated to quantify the stability of crop performance under fluctuating climatic conditions:

$$CRI = \sigma Y / \mu Y$$

where:

- μY = mean simulated yield
- σY = standard deviation of simulated yield

A higher CRI value indicates greater crop resilience and stability under climate variability.

The Monte Carlo simulation was repeated for 1000 iterations to generate a probabilistic distribution of yield outcomes. This enabled the assessment of uncertainty, risk of low-yield events, and system resilience under varying climatic scenarios.

4. Results

4.1 Climate Variability Analysis

The analysis of historical climatic data for Kenya between 1995 and 2024 shows that rainfall patterns show major fluctuations while temperature levels show a steady upward trend. The annual rainfall pattern shows major yearly changes which result in precipitation amounts that vary from 860 mm to 1250 mm according to Figure 1. The years 2000, 2008 and 2016 display distinct periods of low rainfall which show that drought conditions occurred repeatedly during those times. The years 1997, 2020 and 2024 experienced higher rainfall amounts because of beneficial weather patterns that occurred during those years. The temperature trend shown in Figure 2 demonstrates an ongoing rise in temperatures throughout the duration of the research study. The average annual temperature rose from approximately 23.1°C in 1995 to 24.9°C in 2024 which demonstrates a distinct warming pattern. The combination of rising temperatures and low rainfall conditions will result in increased crop stress because higher temperatures will drive up evapotranspiration rates.

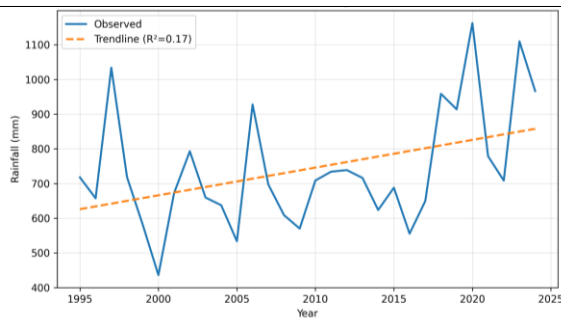


Figure 1: Annual Rainfall Trend (1995–2024)

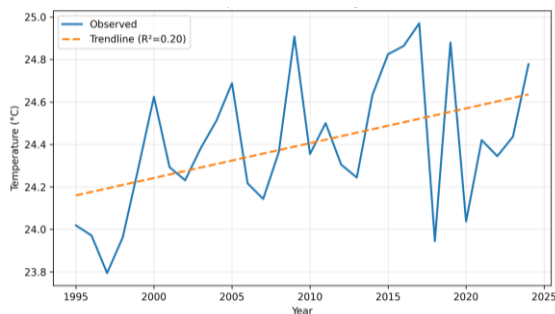


Figure 2: Annual Temperature Trend (1995–2024)

4.2 Crop Yield Variability

The study period shows considerable variability in maize yield data which Figure 3 demonstrates. The yield values show a range between 1.1 t/ha and 1.9 t/ha which demonstrates their sensitivity to different climatic conditions. The yield production decreases during dry periods which experience reduced rainfall. The drought years of 2000 and 2008 produced maize yields which reached 1.2 t/ha while 2009 produced the lowest yield of 1.1 t/ha after multiple low rainfall years (Kouame et al., 2025).

Higher yields occurred during years when rainfall conditions reached their optimal level. The 2004, 2010 and 2018 harvests produced higher yields which reached 1.8 to 1.9 t/ha because the crops performed better through optimal climate conditions. Maize production relies heavily on rainfall availability according to these observations.

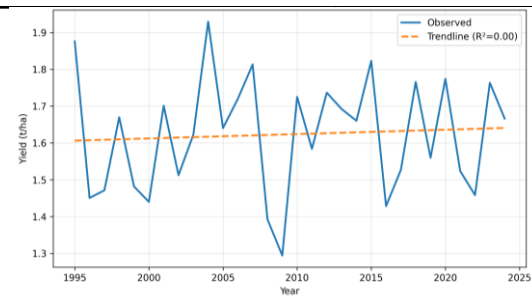


Figure 3: Maize Yield Trend (1995–2024)

4.3 Relationship Between Rainfall and Yield

The relationship between rainfall and maize yield was further examined using correlation and regression analysis, as illustrated in Figure 4. The results indicate a weak to moderate positive relationship between rainfall and maize yield ($r = 0.334$), suggesting that increased rainfall generally contributes to improved agricultural productivity in Kenya. The regression analysis produced a coefficient of determination ($R^2 = 0.11$), indicating that rainfall explains a portion of the observed variability in maize yield, while other environmental and management-related factors may also influence crop performance. Temperature exhibited a weak negative correlation with maize yield ($r = -0.243$), implying that increasing temperature may adversely affect crop growth and productivity. Higher temperatures can increase evapotranspiration and reduce soil moisture availability, thereby intensifying crop stress under low rainfall conditions. Furthermore, rainfall and temperature demonstrated a moderate negative correlation ($r = -0.373$), indicating partial climatic dependence between the variables.

These findings suggest that rainfall remains one of the primary climatic factors influencing maize production in the study area, although crop yield variability is also affected by additional factors such as soil conditions, agricultural practices, and temperature stress. Similar observations regarding the influence of rainfall variability on agricultural productivity

have been reported in previous studies (Baffour-Ata et al., 2023).

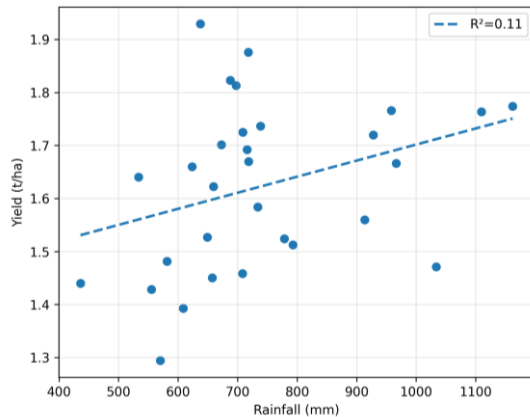


Figure 4: Relationship Between Rainfall and Maize Yield

Table 1: Descriptive Statistics of Climate and Yield Variables

Variable	Mean	Standard Deviation	Minimum	Maximum
Rainfall (mm)	741.87	173.05	436.05	1162.19
Temperature (°C)	24.40	0.32	23.79	24.97
Maize Yield (kg/ha)	1623.43	157.04	1294.30	1929.30

The statistical results show that rainfall displays the highest unpredictable behavior among all the measured variables, which leads to changes in the maize yield. The temperature pattern shows consistent upward movement, while the yield pattern shows moderate changes that climate conditions mainly drive (Rahman et al., 2023).

4.5 Stochastic Simulation Results

The Monte Carlo simulation was performed using the observed historical rainfall and temperature distributions obtained from the NASA POWER dataset. A total of 1000 simulation iterations were conducted within the Excel-based stochastic framework to evaluate the probabilistic behavior of maize

4.4 Statistical Analysis

Descriptive statistical analysis was conducted to quantify variability in the dataset. The results are summarized in Table 1.

yield under varying climatic conditions in Kenya (Tao et al., 2008).

The simulation results indicate that the mean simulated maize yield was approximately 1.62 t/ha with a standard deviation of 0.14 t/ha, reflecting moderate variability in crop productivity under fluctuating climatic regimes. Most simulated yield outcomes were concentrated within the range of approximately 1.4–1.8 t/ha, indicating relatively stable yield behavior under average climatic conditions.

The probability analysis showed that low-yield events (<1.2 t/ha) occurred with an estimated probability of approximately 0.1%, suggesting that extremely poor yield outcomes were relatively infrequent within the simulated



framework. In contrast, high-yield outcomes (>1.8 t/ha) occurred with an estimated probability of approximately **9.6%**, indicating comparatively fewer favorable climatic scenarios resulting in high productivity.

The simulated yield distribution exhibited slight skewness toward lower yield values, highlighting the sensitivity of maize production to adverse climatic variability, particularly rainfall fluctuations and increasing temperature stress. These findings demonstrate the usefulness of stochastic simulation techniques for assessing uncertainty and climate-related agricultural risks under rain-fed farming systems.

4.6 Scenario-Based Analysis

Scenario-based analysis was conducted to evaluate the influence of varying rainfall conditions on maize productivity in Kenya using the observed historical climate dataset (1995–2024). Three climatic scenarios, namely drought, normal, and high rainfall conditions, were defined based on annual rainfall thresholds derived from the NASA POWER dataset. Under drought conditions, characterized by annual rainfall below 900 mm, maize yield exhibited relatively high variability with a mean yield of approximately 1.61 t/ha and a standard deviation of 0.17 t/ha. The minimum yield recorded under drought conditions was approximately 1.29 t/ha, indicating increased vulnerability of rain-fed agricultural systems to moisture stress and unfavorable climatic conditions. Under normal rainfall conditions, corresponding to annual precipitation between 900 mm and 1050 mm, maize yield showed comparatively stable behavior. The mean yield under this scenario was approximately 1.64 t/ha, with reduced variability relative to drought conditions. These rainfall levels provided relatively favorable moisture availability for crop development and supported more consistent agricultural productivity.

High rainfall scenarios, associated with annual precipitation exceeding 1050 mm, produced the highest yield outcomes among the analyzed climatic conditions. The mean maize yield under this scenario was approximately 1.77 t/ha, indicating improved crop performance under enhanced water availability. However, the limited number of high-rainfall years suggests that such favorable climatic conditions occurred less frequently during the study period. The scenario analysis demonstrates that rainfall variability remains a major factor influencing maize yield fluctuations in the study area, while increasing temperature acts as an additional environmental stressor under unfavorable climatic conditions. These findings highlight the importance of adaptive agricultural planning and climate-resilient farming strategies to reduce production risks under changing climatic regimes.

4.7 Crop Resilience Assessment

The Crop Resilience Index (CRI) was used to evaluate the stability and adaptive capacity of maize production systems under fluctuating climatic conditions in Kenya. Based on the simulated yield distribution, the calculated CRI value was approximately **11.57**, indicating a moderate level of resilience within the agricultural system.

The results suggest that maize production systems in the study area possess the capacity to recover under favorable climatic conditions; however, repeated exposure to drought events and rainfall variability can substantially reduce long-term productivity stability. Years characterized by low rainfall and elevated temperature conditions exhibited comparatively lower yield performance, highlighting the sensitivity of rain-fed agriculture to climatic stress.

The moderate CRI value further indicates that although the system demonstrates some



adaptive capacity, increasing climate variability may intensify production risks in the future. These findings emphasize the importance of implementing adaptive agricultural strategies such as improved water management, drought-resistant crop varieties, and climate-informed farming practices to enhance resilience and reduce vulnerability (Marennya et al., 2022).

5. Discussion

The study results demonstrate that climate changes which occur in Sub-Saharan Africa directly affect maize farming in Kenya. Agricultural productivity faces high uncertainty because of two factors which include changing rainfall patterns and rising temperatures. Rainfall emerged as the main climatic factor which determined crop yield because scientists found that higher rainfall amounts directly increased maize production. The results showed that when there were extended periods without rain the crops would experience major losses which proved that rain-fed farming systems suffer from drought risks. The results showed that when rainfall increased during the year crops showed better growth results. Rising temperatures create more problems for farmers because they cause plants to lose water while their resistance to environmental stress decreases when there is not enough rain (Maitah et al., 2021). The stochastic simulation results provide important insights into yield uncertainty because the study shows that low-yield events occur with moderate probability under extreme climatic conditions. The study demonstrates that deterministic methods have operational limitations which make probabilistic agricultural risk assessment models essential. The scenario analysis shows that even small shifts in rainfall patterns result in major changes to crop yield results.

The Crop Resilience Index shows that maize production systems reach moderate resilience

because they can recover during favorable years yet experience decreased stability when faced with multiple drought events. Current agricultural methods fail to provide complete protection against the rising climate variability challenges which agricultural practices face today (Jing et al., 2023). The study introduces Microsoft Excel as a stochastic modeling tool which enables researchers to perform climate-crop relationship analysis through an easy-to-use accessible platform. The model uses historical data as its main source while it fails to consider additional factors which include soil conditions and farm management practices.

Prior to stochastic simulation, the statistical characteristics of rainfall and temperature datasets were examined to evaluate the suitability of normal distribution assumptions. Distribution analysis was performed using histogram inspection and descriptive statistical measures. In addition, normality testing was conducted using the Shapiro–Wilk criterion to assess whether the climatic variables approximately followed normal distributions. The results indicated that the rainfall and temperature datasets did not show significant deviations from normality at the selected temporal scale, supporting the use of normal probability distributions in the Monte Carlo framework.

The Monte Carlo simulation was performed using 1000 iterations. Although larger iteration numbers may provide marginal improvements in distribution smoothness, previous studies have demonstrated that 1000 iterations are generally sufficient for stable estimation of mean values and probability distributions in Excel-based stochastic models. Convergence of the simulated mean yield values was observed within the selected iteration range, indicating acceptable model stability and computational efficiency.



The correlation analysis revealed that rainfall has a moderate positive influence on maize yield, confirming the importance of precipitation availability in rain-fed agricultural systems. Temperature exhibited a weak negative relationship with yield, indicating that increasing thermal stress may contribute to productivity decline. Furthermore, the moderate negative correlation between rainfall and temperature suggests partial interdependence between climatic variables, which may influence agricultural outcomes under changing climatic regimes.

In addition, the stochastic model assumes simplified probabilistic relationships between climatic variables and treats rainfall and temperature independently during simulation. Future studies may improve model accuracy by incorporating multivariate simulation approaches and climate covariance structures.

6. Conclusion and Policy Recommendations

6.1 Conclusion

This study examined the impact of climate variability on maize production in Kenya using an integrated Excel-based stochastic modeling framework. The analysis of a 30-year dataset showed that rainfall patterns underwent significant changes while temperatures showed a steady increase which resulted in major effects on agricultural productivity. The findings demonstrate that maize yield is highly sensitive to climatic conditions, particularly rainfall variability, which emerged as the dominant factor influencing crop performance. The results show that periods of low rainfall lead to decreased yields while favorable rainfall conditions result in higher productivity. The observed upward trend in temperature further intensifies crop stress, especially when combined with inadequate rainfall. The stochastic simulation results show that yield outcomes contain substantial uncertainty which includes a significant chance

of low-yield events occurring under severe climatic conditions. The study demonstrates how climate variability makes rain-fed agricultural systems more vulnerable to environmental changes.

The Crop Resilience Index (CRI) developed in this study shows that maize production systems achieve moderate resilience. The system experiences decreased stability with repeated drought events although it can recover during times of favorable weather conditions. The research demonstrates that Microsoft Excel functions as an effective and user-friendly software tool which enables users to create stochastic models for use in environments with restricted data access.

The research demonstrates that agricultural planning needs adaptive approaches which combine risk assessment methods to build resilience and protect food security during climate change.

6.2 Policy Recommendations

The study's findings lead to several policy recommendations which aim to strengthen agricultural resilience in Kenya and other Sub-Saharan African areas. The first step requires implementing climate-resilient agricultural methods which involve farmers adopting drought-resistant crop varieties and advanced seed technologies. The implemented measures will decrease crop production sensitivity toward rainfall changes while improving yield performance during challenging weather situations. Water resource management requires funding as its second priority. The implementation of small-scale irrigation systems together with rainwater harvesting methods and efficient water management techniques will decrease reliance on rainfall while protecting against drought effects.

Farmers can use climate information and early warning systems to make informed choices when they become available. The delivery of



accurate weather forecasts together with seasonal outlooks and risk advisories enables farmers to modify their planting times while implementing suitable management techniques. The agricultural sector requires enhanced capacity development through educational programs which should include both farmers and stakeholders. Training people to use basic decision-support tools like Excel-based stochastic models will help them better understand climate risks and make smarter adaptive choices.

The fifth recommendation suggests that policymakers should promote the use of digital technologies and data analysis tools for agricultural development planning. Resource-limited areas can benefit from affordable and easily accessible platforms which enable research to be applied in real-world situations.

Consent For Publication

Not applicable. This chapter does not contain any person's data, images, or identifiable information. All content is based on secondary sources, technological analyses, and publicly available information.

Conflict Of Interest

The authors declare no conflict of interest with respect to the research, authorship, and/or publication of this chapter.

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