Research on World Agricultural Economy
https://journals.nasspublishing.com/index.php/rwae

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Climate Change and Crop Production Vulnerability in Somalia: A VECM Analysis for Sustainable Agriculture

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ABSTRACT

Somali crop production is vulnerable to climate change, as agriculture is heavily reliant on rainfall. Increased temperatures, sporadic rainfall, and higher levels of CO_2 emissions threaten food security as well as the livelihoods in rural areas. While global studies discuss these issues, there is a lack of empirical research on Somalia. This research attempts to study the gap created by the absence of research regarding the vulnerability of crop production to climate change and its sustainable agriculture aspects. The study uses a vector error correction model (VECM) to evaluate how climate factors, including temperature, rainfall, CO_2 emissions, land designated for agriculture, and labour, affect crop production in the short and long term. The study found that CO_2, temperature, and rainfall lead to boosted crop production in the short term because of the traditional adaptation strategies employed by farmers. In the long term, a 1% increase in CO_2 emissions leads to a 57% reduction in crop production, and a similar rise in temperature causes production levels to fall over 100%. Rainfall, agricultural land, and labour continue to positively influence production levels in both periods. These results strongly indicate the necessity of climate-resilient strategies, better irrigation systems, and new forms of farming. The promotion of climate-smart agriculture will help mitigate the negative effects of climate change on the agricultural sector of Somalia while simultaneously catering to the issue of food security.

Keywords: Crop Production; Climate Change; VECM; Cointegration; Equilibrium

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ARTICLE INFO
Received: 6 March 2025 | Revised: 9 April 2025 | Accepted: 15 April 2025 | Published Online: 16 July 2025
DOI: https://doi.org/10.36956/rwae.v6ix.1815

CITATION
Nur, A.M., Ali, A.Y.S., 2025. Climate Change and Crop Production Vulnerability in Somalia: A VECM Analysis for Sustainable Agriculture. Research on World Agricultural Economy. 6(3): 355–369. DOI: https://doi.org/10.36956/rwae.v6ix.1815

1. Introduction

Globally, climate change affects agricultural productivity through mechanisms such as higher average temperatures, more frequent and severe droughts, changes in precipitation patterns, and increased levels of atmospheric CO_2. Key economic sectors that rely on natural resources, such as agriculture, fisheries, livestock, forestry, and tourism, view climate change as a major obstacle [1]. Additionally, climate change and its environmental effects are occurring at an unprecedented rate, posing challenges for governments and societies in adapting to and managing these changes. These shifts are progressively destabilizing livelihood systems for billions of people worldwide [2].

Regarding the impact of climate change on agriculture, studies have highlighted the vulnerability of different regions and underscored the urgent need for adaptation strategies. Karimi, Karami and Keshavarz [3] revealed the effects of climate change on agriculture in Asia, particularly Iran's vulnerability, and the need for adaptation efforts by governments and farmers. Similarly, Aryal et al. [4] stressed the criticality of adaptation in South Asia to maintain agricultural productivity. Trinh [5] demonstrated the significant impact of climate change on Vietnamese agriculture, advocating for proactive measures. Huong, Bo and Fahad [6] projected substantial revenue declines in Northwestern Vietnam without adaptation, highlighting the need for resilience strategies. Jawid [7] suggested that future climate change could have a potentially positive effect on agriculture, emphasizing the complex relationship between climate and agriculture. Ahsan, Chandio and Fang [8] provided insights into the factors affecting cereal crop production, suggesting that adaptation and institutional support are vital for sustainable agriculture.

In Africa, Kogo, Kumar and Koech [9] emphasized the urgent need for adaptive strategies in arid and semi-arid areas due to climate change's ongoing and future negative impacts on crop production and food security. Similarly, Kalele et al. [10] highlighted significant adverse effects on farmers' livelihoods in Kenya's Yatta region from climate-related events like drought, crop diseases, and floods, despite low adoption rates of on-farm adaptation strategies such as water conservation and harvesting. Furthermore, Onyeneke et al. [11] observed a negative impact of climate change on crop outputs in Nigeria, noting that while land positively correlated with crop outputs in the long run, temperature negatively affected several crops, and rainfall had mixed effects.

Abera et al. [12] predicted a decline in maize yields in Ethiopia, and Kichamu et al. [13] examined the challenges faced by smallholder farmers in Kenya in adapting to climate change. Waaswa et al. [14] emphasized the importance of Climate-Smart Agriculture for achieving sustainable development goals and improving potato yields. These studies underscore the pressing need for local adaptation strategies and knowledge to mitigate the impact of climate change on agriculture in Africa.

In Somalia, Warsame et al. [15] highlight the detrimental effect of climate change on crop yields, emphasizing the long-term impacts of temperature, rainfall, and political instability on sorghum production. They find that temperature, political instability, and agricultural labor negatively influence sorghum production, while rainfall and the area under sorghum cultivation have a positive impact. Warsame et al. [16] find that rainfall positively influences crop production eventually but negatively affects it in the short run, while temperature impacts crop production negatively in the short and long run. They also emphasize the need for coherent policies to address the impacts of climate change and promote sustainable agriculture in Somalia. Furthermore, Nur [17] recommends improving the institutional framework through agricultural investment to achieve sustainable food security.

Somalia's economy is predominantly agricultural and suffers from strong impacts of climate change. This is largely because the country relies on rainfall agriculture coupled with recurrent climatic shocks like droughts, floods, and locust invasions. Somalia suffers from poorly developed institutions and low inflows of investment for climate change adaptation, further complicating the situation. These shifts, whether acknowledged or not, will continuously obstruct agricultural economic growth, threatening food production for millions along with their livelihoods in Somalia.

The studies conducted on Somalia's agricultural susceptibility to climate change show that there are gaps on the issue, particularly when compared to the extensive research done in other regions of Africa and Asia. Locally, research has leaned towards studying climate variability over very short periods but has not given significant attention to rising temperatures, CO_2 emissions, changing rainfall patterns, and their long-term impacts on plant growth and productivity. Additionally, little attention has been given to some macroeconomic elements like the availability of land, the amount of labor, and the state of governance and how they determine the level of resilience of the agricultural sector in Somalia. Thus, more attention needs to be given to studying how climate change in Somalia interacts with other socio-economic and political conditions, especially their impact on the agricultural resilience of the country.

This study seeks to address the gaps in research by analyzing Somalia's exposure to climate change concerning crop production. In particular, this study examines how climatic factors, specifically temperature, CO_2 emissions, and rainfall, affect crop yields alongside macroeconomic considerations such as land and labor supply. In addition, the study provides policy adaptation plans and climate resilience recommendations for Somalia's agricultural sector. This study addresses the identified gaps in adaptation strategies aimed at enhancing climate change resilience in Somalia's agricultural systems. The critical overarching research question for this study is: What approaches can be formulated for Somalia to evade, reduce, and mitigate climate change effects in maintaining agricultural productivity and food security sustainability?

This analysis is expected to be useful to policymakers, agriculture administrators, and development partners in devising appropriate policy responses and long-term adaptation plans for the agricultural sector. This study's results contribute not only to an understanding of the adaptation challenges of Somalia's climate change but also provide sustainable articulation on the preservation of the agricultural economy and food supply to the population amid climate change stressors.

2. Empirical Review

The studies on climate change's impact on agriculture offer comprehensive insights into the complex challenges it poses on agricultural production in various regions. The study conducted by Warsame et al. [15] explored the patterns of sorghum production in Somalia over the period of 1980 to 2017. Their research indicates that rising temperatures, political instability, and heightened agricultural labor requirements are associated with a decrease in sorghum yield. Conversely, augmented precipitation levels and expanded agricultural land usage exhibit a favorable impact on sorghum production.

In another study, Warsame et al. [16] found that while rainfall positively affects crop production in the long run in Somalia, it has a negative impact in the short run. Temperature consistently negatively affects production, while CO_2 levels do not significantly influence crop output.

Karimi, Karami and Keshavarz [3] also studied precipitation, temperature, and CO_2 levels, going over the literature to see how these would affect agricultural yields, water needs, and farm family incomes. Using an integrated modeling approach, Dudu and Çakmak [18] evaluated the economic effects of climate change on Turkey and projected that, although the economy might not be notably impacted until the late 2030s, negative effects are expected to increase in the second half of the century, especially in the agricultural sector.

Abera et al. [12] emphasized the need for tailored adaptation strategies, demonstrating through estimation that maize yields may decline by up to 43% and 24% in two specific locations while potentially increasing by 51% in another by the end of the century. Using the decision support system for agrotechnology transfer (DSSAT) crop model, they simulated maize growth in Ethiopia across current and projected climate scenarios. Simultaneously, Kogo, Kumar and Koech [9] scrutinized the ramifications of climate change on food security and crop productivity in Kenya. They emphasized the vulnerability of communities residing in arid and semi-arid regions, as well as the importance of adaptive measures in addressing challenges arising from population expansion and climate variability.

In a semi-arid area of Kenya, Kichamu et al. [13] investigated factors influencing their ability to adapt. They found that past weather extremes shape farmers' perceptions, despite obstacles like inadequate technical knowledge and financial resources, leading to strategic responses to manage climate risks. Over 39 years, Onyeneke et al. [11] studied the effects of climate change on six important crops in Nigeria. While temperature negatively affects several crops, land has a positive long-term effect on most crops, and they found that policies to improve credit availability, encourage accurate fertilizer use, and develop climate-resilient crop varieties are all necessary. Finding that while CO_2 emissions increase agricultural productivity, temperature, and rainfall have detrimental long-term effects, Chandio et al. [19] highlight the urgent need for customized adaptation techniques and sustainable practices to guarantee food security. Comparably, Kogo, Kumar and Koech [9] stress the need to improve farmers' adaptation capacity to tackle population growth and climate change in Kenyan agriculture.

Examining farmers' perceptions in Bhutan, Chhogyel et al. [20] reveal insights into climate change adaptation strategies, emphasizing the importance of sustainable farming practices. Meanwhile, Waaswa et al. [14] conducts a review to identify factors influencing Climate-Smart Agriculture (CSA) practices in potato production, emphasizing the importance of financial, natural, physical, and social capital in successful adoption and impact, highlighting the need for tailored CSA practices that consider farmers' needs, communication methods, and socioeconomic factors. In an editorial, Arora [21] highlights the urgency of climate adaptation measures and mitigation strategies in agriculture to address climate change's impact on food security. Additionally, Aryal et al. [4] suggest the necessity of strengthening institutional setups for implementing agricultural practices for climate change adaptation in South Asia.

Using panel data and the Ricardian method, Trinh [5] looked at how climate change affects Vietnamese agricultural output at the household level. The research indicated that while more precipitation only damages irrigated farms in the Central and South areas, greater temperatures help farms in the warmer southern regions during the dry season. In the rainy season, increasing temperatures eventually reduce net income for irrigated farms, while additional rainfall only helps farms in the North; future climate models indicate that the effects on farmers would vary. Additionally, Fitton et al. [22] assessed the vulnerability of crops and grasslands to water scarcity worldwide, suggesting that addressing dietary changes, such as reducing food waste and decreasing meat consumption, could help mitigate land loss and food insecurity caused by water scarcity. Challinor et al. [23] presented criteria for using crop models to assess climate change impacts, emphasizing the importance of framing research questions and using appropriate methods. They highlighted good practices like developing and documenting crop models, forming crop-climate ensembles, and assessing adaptation options, emphasizing stakeholder engagement and methodological diversity for improved risk assessments in agriculture. Building on this, Ahsan, Chandio and Fang [8] investigated the impact of CO_2 emissions, energy consumption, cultivated area, and the labor force on cereal crop production in Pakistan from 1971 to 2014. They found long-term positive effects on production from these factors and identified bidirectional causality between CO_2 emissions and cultivated areas.

Similarly, Huong, Bo and Fahad [6] projected large revenue drops in Northwestern Vietnam's agriculture using the Ricardian framework. In a similar context, Maia, Miyamoto and Garcia [24] studied the impact of extreme climate events on agricultural production in São Paulo state, Brazil, suggesting that technological advancements and environmental preservation can enhance resilience. This underscores the importance of adaptive strategies, as highlighted by Jamshidi et al. [25], who examined smallholder farmers' vulnerability in Iran's Hamadan province, identifying factors such as education and income. Markou et al. [26] evaluate crop adaptation techniques to mitigate climate change impacts, emphasizing proactive strategies. Meanwhile, Agovino et al. [27] investigate the relationship between climate change, agriculture, and sustainability in EU-28 countries, highlighting negative bidirectional relationships between climate change and agricultural yields. This underscores the need for policy interventions to promote sustainable practices. Crick et al. [28] explore how governments can create an enabling environment for private sector adaptation in sub-Saharan Africa, emphasizing the need for infrastructure and access to finance to support adaptation efforts.

Additionally, Asumadu-Sarkodie and Owusu [29] study the relationship between carbon dioxide emissions and agricultural practices, noting bidirectional causality. Moreover, Kalele et al. [10] examine climate change impacts on farmers' livelihoods, noting low adoption rates of adaptation strategies. This highlights the importance of understanding and addressing barriers to adaptation. Similarly, Makuvaro et al. [30] explore smallholder farmers' perceptions of climate change in Zimbabwe, emphasizing the need for self-directed adaptive strategies.

Further afield, Jawid [7] investigates the economic impact of climate change on agriculture in Afghanistan's Central Highlands, finding significant effects of temperature and precipitation changes on crop net revenue. Arnell and Freeman [31] evaluate climate change impacts on agriculture in the UK, projecting changes in climate resources and hazards with implications for crop production and risk management. This underscores the need for initiative-taking adaptation strategies in agricultural practices.

Adamseged, Frija and Thiel [32] analysed the changes in the rural economies of Ethiopia, paying particular attention to rainfall and other econometric variables. Rainfall negatively affects the household's participation in non-farm economy activities, especially in wage-earning employment. Family members' socio-economic characteristics, like age, gender, and other demographics, are important in making livelihood choices. Some communities are better than others in terms of infrastructure and marketing facilities, which creates different living standards. This study also argues that policies aimed at improving non-farm livelihood strategies should be viewed as a primary means of rural development, rather than solely as a method of climate adaptation.

Samatar [33] examined the factors that influence agricultural productivity in Somalia using an Autoregressive Distributed Lag (ARDL) model. The major factors are rainfall variability, credit readily available to farmers, and modern farming practices. The results show that there are indeed shocks to the yields in the short term, but to improve them in the long term, there needs to be investment in structural, financial, and technological resources within the country. The results suggest that policies need to be directed towards credit expansion and the adoption of more modern agricultural methods to enhance productivity in Somalia in the long term. Additionally, Samatar [34] mapped the impacts of climate change on Somalia's pastoralists and their livestock productivity, arguing that rising temperatures combined with unpredictable rainfall patterns and extended drought periods are detrimental to pastoral livelihoods. The research highlights the necessity for adaptive measures such as enhanced water management and policy integration to address climate-related risks.

In a different study, Samatar [35] analysed the impact of climate change on agriculture in Somalia, arguing that changes in precipitation and average temperature interfere with farming output. The results reinforce the need for more comprehensive farming models that are resilient to climate, and also policy actions for food security and rural development.

Although previous empirical studies provide much useful information on climate change and its impacts on agriculture, there is a literature gap in most studies concerning Somalia. As an example, Warsame [34] and Warsame et al. [16] look at the consequences of heightened political temperatures and ongoing politics on sorghum farming in Somalia. Most of these studies look at the existence of climatic conditions but do not consider the implications of the climate's variability and macroeconomic factors impacting agriculture, such as land and labor.

In a more recent study, Samatar [35] assessed climate change effects on Somalia's pastoralists and farmers in two distinct studies. Although these works illustrate the damaging effects of changing temperatures and irregular rainfall on livestock and crop production, there are no econometric models given to estimate these impacts. This study cannot derive actionable insights that would facilitate policy development without applying formidable econometric analyses.

This study would fill in these gaps by utilizing an advanced econometric tool, the Vector Error Correction Model (VECM), which captures short-term scenarios and long-term equilibria. This tool helps this research because many variables must be handled simultaneously because they influence each other. This approach marks a significant improvement over simpler econometric techniques that were the basis of many previous studies, providing a more precise and context-relevant analysis of Somalia's agricultural problems.

Also, although prior studies had looked at different parts, there is a significant lack of research concerning the particular exposures of Somalia. This study uses VECM in an attempt to bridge this gap by examining climate change effects on agricultural productivity in Somalia, as well as offering essential policy suggestions aimed at improving resilience and sustainability.

3. Methodology

3.1. Theoretical Framework

Analyses regarding the agriculturally focused economy of Somalia can employ the relevant economic and agricultural models to comprehend the effects of climate change on the vulnerability of crop production. In particular, the Ricardian model [36] permits the evaluation of the effects of temperature and precipitation changes on the productivity of land and also suggests the adaptation of the farmer to minimize the climate impact. The Cobb-Douglas production function [37] accounts for productivity as a function of agriculture's basic inputs of land, labour, and capital, all having climate as an external factor which performs the role of shocks for productivity. Farmers coping with climate stress through day-to-day agricultural and managerial innovations are being viewed through the induced innovation theory [38]. The environmental Kuznets curve [39], on the other hand, acknowledges that economic growth has a negative impact on the environment, much in the same way that CO_2 emissions have for agriculture over time.

In addition, the Harris-Todaro migration model [40] focuses on the temporally migrant laborers moving into urban areas due to climatic changes, and the subsequent neglect of productivity in farming, which is also disregarded for a lengthy period. These theoretical approaches assist in the comprehension of the multifaceted relation which exists between the change in climate and agriculture, focusing particularly on crop production and sustainable farming practices in Somalia.

3.2. Data Source

This study investigates the vulnerability of crop production to climate change in Somalia, with implications for sustainable agriculture. The study uses time-series data from 1990 to 2022. It analyzes data from the World Bank, the FAO, and the SESRIC. Crop production (CRP) is the dependent variable, influenced by several key factors. The study expects average temperature (AMT) and CO_2 emissions (CO_2) to have negative relationships with crop production, as higher temperatures and excessive CO_2 can adversely affect crop yields. On the other hand, the study anticipates a positive relationship between annual average rainfall precipitation (RF) and crop production, as adequate rainfall is crucial for plant growth. The study also expects agricultural land (AL) and labor (L) to positively influence crop production, as they can facilitate more efficient farming practices and higher yields.

3.3. Variables Measurement, Notations, Expected Sign and Source

Table 1 presents the key variables used in this study, and every variable has its name, measurement unit, notation, expected theoretical sign, and data source.

Table 1. Variables measurement and notations.

Variable Name	Measurement	Notation	Expected Sign	Source
Crop production	Measured in thousand tons	CRP	Dependent variable	WDI
Average temperature	Measured in degrees Celsius	AMT	Negative (−)	FAO
CO_2 emissions	Measured in kilotons	CO_2	Negative (−)	FAO
Annual average rainfall	Measured in millimeters Precipitation	RF	Positive (+)	FAO
Agricultural land	Measured in hectares	AL	Positive (+)	WBI
Labor	Measured in millions of individuals	L	Positive (+)	SESRIC

3.4. Econometric Methods and Modelling

In this study, the analysis incorporated the vector error correction model (VECM) to study the temporal association of climate change components like temperature, CO_2 emissions, and rainfall against the economic factors (land and manpower). The selection of VECM, as opposed to other econometric techniques such as ARDL and VAR models, is underpinned by three primary reasons. Firstly, VECM permits the specification of both short-run dynamics and long-run equilibrium relationships. This is particularly relevant where the variables are found to be cointegrated. Secondly, there are a significant number of variables—temperature, CO_2 emissions, rainfall, and agricultural land—that are stationary at the first difference level, while labor is the second difference. VECM is typically used for I(1) variables; however, it is also appropriate with I(2) variables because VECM offers sufficient conditions to impose suitable lags and enable capturing short-run movements. The Johansen cointegration test supported the existence of long-run relationships among the analyzed variables by finding six cointegration equations. This further affirms the selection of VECM. Later on, this will be useful when determining how agricultural production in Somalia is affected by CO_2 emissions, temperature, and rainfall alongside other climate change factors over a period of time. The VECM model has been selected as optimal for the analysis because it is able to capture short-term fluctuations and long-term trends. The ARDL model, on the other hand, may be useful in some cases for the integration, particularly in the presence of mixed orders of integration. Sadly, it is inapplicable owing to the I(2) variable. That model seems to be specialized in requiring variables to be I(1), or some mix of I(0) and I(1).

This study employs a model framework similar to the ones employed by Chandio et al. [19], Warsame et al. [16] and Samatar [33]. It combines climate change variables (like temperature, carbon emissions, and rainfall) with important factors like agricultural labor and the land used for agricultural production. To explore how climate change factors such as CO_2 emissions, temperature, and rainfall affect agriculture, the study specifies the following model:

$$CRP_t = f\left(RF_t, CO_{2t}, AMT-_t, AL_t, L_t\right) \tag{1}$$

Equation (1) represents a functional relationship where crop production (CRP) at time t is a function of rainfall (RF), CO_2 emissions (CO_2), average temperature (AMT), agricultural land (AL), and labor (L).

$$lnCRP_t = \beta_0 + \beta_1 lnRF_t + \beta_2 lnCO_{2t} + \beta_3 lnAMT_t + \beta_4 lnAL_t + \beta_5 lnL_t + \varepsilon_t \tag{2}$$

Equation (2) specifies the logarithmic transformation of crop production (CRP) at time t as a linear function of the logarithmic transformations of rainfall (RF), CO_2 emissions (CO_2), average temperature (ATM), agricultural land (AL), and labor (L).

$$\Delta y_t = \alpha\beta' y_{t-1} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + \cdots + \Gamma_{p-1} \Delta y_{t-(p-1)} + \Pi y_{t-1} + \varepsilon_t \tag{3}$$

Equation (3) represents a VECM, where is the change in the vector of variables at time are the adjustment coefficients, are the cointegrating vectors, are the adjustment coefficients for the first differences, is the matrix of cointegrating vectors, and is the error term.

$$Trace = -\mathrm{T}\sum_{i=r+1}^{n} \ln(1-\lambda_i) \tag{4}$$

Equation (4) uses Trace statistics in the Johansen cointegration test to determine the number of cointegrating relationships among the variables, where are the eigenvalues.

$$Max\ Eigenvalue = -\mathrm{T}\ln(1-\lambda_{r+1}) \tag{5}$$

Equation (5) the maximum eigenvalue statistic is another test statistic used in the Johansen cointegration test to determine the number of cointegrating relationships (r) among the variables.

$$y_t = \alpha_1 \beta_1' y_{t-1} + \alpha_2 \beta_2' y_{t-2} + \cdots + \alpha_r \beta_r' y_{t-r} \tag{6}$$

Equation (6) represents the long-run equilibrium relationship among the variables, where $\alpha_i$are the adjustment coefficients that determine the speed of adjustment to the long-run equilibrium.

$$Speed\ of\ Adjustment_{\ i} = -\ln(1 - \alpha_i) \tag{7}$$

Equation (7) measures how quickly the i^{th} variable adjusts to its long-run equilibrium relationship as specified by the cointegrating vectors. A higher value of α_i indicates a faster adjustment speed, meaning that the variable returns to its equilibrium relationship more rapidly in response to deviations from the long-run equilibrium.

4. Empirical Results and Discussions

4.1. Descriptive Statistics of Summary

Table 2 presents the descriptive statistics for six variables related to crop production in Somalia. The average crop production (CRP) across 33 observations is approximately 96.61 units, with a standard deviation of 11.81, indicating a relatively narrow spread around the mean. The average temperature (AMT) has a mean of around 26.95 and a small standard deviation of 0.184, suggesting minimal temperature variation. Carbon emissions (CO_2) average about 629.091 units, with a standard deviation of 77.11, indicating a more noticeable spread. Agricultural land (AL) has an average area of approximately 1,090,969.7 units and a standard deviation of 86,448.86, indicating a moderate level of variability. Labor (L) averages about 1,975,676.7 units, with a standard deviation of 597,951.05, suggesting a substantial spread. Rainfall (RF) averages around 278.49 units, with a standard deviation of 27.53, indicating a moderate level of variability in rainfall amounts.

Table 2. Descriptive summary of statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
CRP	33	96.606	11.814	71.49	131.77
AMT	33	26.952	0.184	26.6	27.34
CO_2	33	629.091	77.11	490	810
AL	33	1,090,969.7	86,448.859	1,000,000	1,350,000
L	33	1,975,676.7	597,951.05	1,154,177	3,163,183
RF	33	278.494	27.527	230.24	348.67

Note: E stands for exponent.

4.2. Unit Root Test

Table 3 presents the results of the ADF and PP tests for crop production (CRP), rainfall (RF), average temperature (AMT), agricultural land (AL), and labor (L) in Somalia. The findings indicate that CRP, RF, AMT, and AL are stationary at the first difference, supported by significant ADF and PP test results at the 1% or 5% levels. In contrast, L shows stationarity only at the second difference, which is significant at the 1% level. This means that the integration of CRP, RF, AMT, and AL is of order 1 (I(1)), while the integration of L is of order 2 (I(2)), indicating that the statistical properties remain the same over time based on the different orderings.

Table 3. ADF and PP test statistics.

Augmented Dickey-Fuller			Phillip–Perron		I. Order
Variables	**Level**	**Difference**	**Level**	**Difference**	
CRP	−4.528***	−7.232***	−4.651***	−7.955***	I(1)
RF	−2.984**	−11.163***	−5.187***	−22.987***	I(1)
CO_2	0.283	−2.876*	−0.764	−2.737*	I(1)
AMT	−3.660***	−8.470***	−3.614**	−25.397***	I(1)
L	2.329	−7.967***	4.660	−7.635***	I(2)
AL	−3.147**	−4.316***	−2.225	−5.308***	I(1)

Note: *** p < 0.01, ** p < 0.05, * p < 0.1.

4.3. Correlation Test

Table 4 illustrates that there are weak to moderate positive links between crop production (CRP), rainfall (RF), labor (L), carbon emissions (CO_2), average temperature (AMT), and agricultural land (AL) in Somalia. These correlations indicate that changes in one variable trigger corresponding changes in others, with the strength of these relationships varying. The results imply potential interdependencies and influences among the variables.

Table 4. Correlation result.

	CRP	RF	L	CO_2	AMT	AL
CRP	1					
RF	0.273	1				
L	0.368	0.448	1			
CO_2	0.282	0.147	0.578	1		
AMT	0.285	0.304	0.604	0.222	1	
AL	0.352	0.148	0.207	−0.087	0.283	1

4.4. Lag Selection Criteria

Table 5 outlines the selection process for determining the optimal lag length in the model. Adding one lag (lag 1) made the model fit better than not having any lags (lag 0), as shown by higher log-likelihood and lower values for the Akaike Information Criterion (AIC), the Schwarz Information Criterion (SC), and the Hannan-Quinn Information Criterion (HQ). However, the inclusion of a second lag (lag 2) did not result in a significant improvement in the model fit. As a result, the study determines that one (lag 1) is the model's optimal lag length.

Table 5. VECM lag selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−1242.039	NA	3.75e+27	80.519	80.796	80.609
1	−1068.509	268.691	5.51e+23	71.646	73.589*	72.279
2	−1023.920	51.781*	4.20e+23*	71.091*	74.600	72.268*

Note: E stands for the exponent and * stands for the selected lag.

4.5. Cointegration Test

Table 6 presents Johansen's cointegration results, indicating cointegration among the variables. The trace test rejects the hypothesis of no cointegration at all significance levels for each rank, confirming cointegration. Similarly, the maximum eigenvalue test rejects the null hypothesis, further supporting cointegration. Later studies can model these long-term equilibrium relationships between the variables using vector error correction models (VECM).

Table 6. Johansen cointegration trace and eigenvalue results.

Hypothesis	Eigenvalue	Trace Statistic	5% Critical Value	Prob.**
Trace Result				
0*	0.727	132.484	95.754	0.000
1 *	0.707	93.548	69.819	0.000
2 *	0.510	56.752	47.856	0.006
3 *	0.462	35.351	29.797	0.010
4*	0.336	16.731	15.495	0.032
5 *	0.137	4.426	3.841	0.035
Maximum Eigenvalue Result				
0*	0.726	38.936	40.077	0.067
1 *	0.707	36.796	33.877	0.022
2 *	0.510	21.401	27.584	0.253
3 *	0.462	18.620	21.131	0.108
4*	0.336	12.305	14.264	0.099
5 *	0.137	4.426	3.841	0.035

Note: * Stands selected rank.

4.6. VECM Estimation

Table 7 illustrates the short-term dynamics, indicating that increases in CO_2, temperature, rainfall, agricultural acreage, and labor enhance crop output in Somalia. For every percentage change in CO_2, crop productivity rises by 4.8%, with similar effects for temperature and rainfall. Interestingly, higher temperatures in Somalia correlate with increased agricultural output because they use traditional adaptation techniques. Rainfall, humidity, and sunshine also influence the relationship between temperature and crop output.

Table 7. VECM short-run dynamics results.

VARIABLES	(1) D_lnCRP	(2) D_lnCO_2	(3) D_lnAMT	(4) D_lnRF	(5) D_lnAL	(6) D_lnL
L._ce1	−0.014	−0.006	−0.003***	0.050***	0.005	−0.001
	−0.017	−0.005	−0.001	−0.013	−0.010	−0.002
LD. lnCRP	0.001	0.048	0.008	0.360**	0.089	0.056**
	−0.219	−0.064	−0.012	−0.173	−0.125	−0.026
LD. lnCO_2	−0.525	0.497***	−0.031	0.487	0.292	−0.042
	−0.544	−0.158	−0.031	−0.430	−0.310	−0.065
LD. lnAMT	3.284	1.574	−0.028	−10.970***	0.064	0.166
	−3.628	−1.053	−0.204	−2.867	−2.066	−0.436
LD. lnRF	−0.106	−0.079*	−0.005	−0.459***	−0.045	0.012
	−0.163	−0.047	−0.009	−0.129	−0.093	−0.020
LD. lnAL	−0.201	−0.182*	0.045**	−0.316	0.093	0.001
	−0.380	−0.110	−0.021	−0.300	−0.216	−0.046
LD. lnL	−0.035	0.097	−0.063	0.236	0.018	0.101
	−1.681	−0.488	−0.095	−1.328	−0.957	−0.202
Constant	0.007	0.002	0.002	0.002	0.002	0.029***
	−0.056	−0.016	−0.003	−0.044	−0.032	−0.007
Mean dependent var	3.294		SD dependent var		0.007	
Number of obs	31.00		Akaike crit. (AIC)			

Note: Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 8 presents the model's long-run dynamics, which show that percentage changes in the natural logarithms of carbon emissions (CO_2) and average temperature (AMT) in Somalia are associated with reductions in crop production. Specifically, a percentage increase in CO_2 will cause a decrease in crop production of approximately 57%, whereas a similar increase in AMT is associated with a decrease of over 100%. Therefore, both CO_2 and AMT exhibit negative statistical significance for crop production in Somalia at the 1% level.

However, there is a correlation between higher natural logarithms of rainfall (RF), agricultural land (AL), and labor (L). A percentage change in rainfall corresponds to a crop production increase of around 70%, while similar increases in agricultural land and labor are associated with approximately 12% and 68% increases, respectively. Therefore, RF, AL, and L demonstrate positive statistical significance for crop production in Somalia at the 1% critical level, except for the variable representing agricultural land (AL).

Table 8. VECM long-run dynamics results.

Beta	Coefficient	Std. Errs.	Z	P > Z	[95% Conf. Interval]	
_ce1						
lnCRP	1					
lnCO_2	5.786	1.497	3.870	0.000	2.852	8.720
lnAMT	300.536	33.092	9.080	0.000	235.676	365.396
lnRF	−7.617	2.495	−3.050	0.002	−12.507	−2.726
lnAL	−1.235	1.789	−0.690	0.490	−4.743	2.272
lnL	−6.846	0.982	−6.970	0.000	−8.770	−4.922
_cons	−872.720					

4.7. Normality Test

Table 9 outlines the Jarque-Bera test on lagged natural logarithm variables (CRP, CO_2, AMT, AL, L, and RF). The findings indicate that most variables (CRP, CO_2, AMT, AL, L) are normally distributed, as their respective p-values exceed 0.05, providing insufficient evidence to conclude that they do not adhere to a normal distribution. However, RF does not follow a normal distribution, and substantial evidence suggests that it deviates from a normal distribution, leading to the rejection of the null hypothesis.

Table 9. Normality test.

Equation	χ^2	df	Prob > χ^2
D_lnCRP	0.032	2	0.984
D_lnCO_2	1.594	2	0.451
D_lnAMT	0.575	2	0.750
D_lnRF	11.131	2	0.004
D_lnArL	0.117	2	0.943
D_lnL	0.817	2	0.665
ALL	14.267	12	0.284

4.8. Autocorrelation Test

Table 10 summarizes the results of the LAgrange-Multiplier test for autocorrelation at lag orders 1 and 2. At lag order 1, the test indicates a rejection of the null hypothesis of no autocorrelation, with a p-value of 0.019, which is below the typical significance level of 0.05. This suggests that there is autocorrelation at lag order 1. However, at lag order 2, the test does not provide sufficient evidence to reject the null hypothesis of no autocorrelation, as the p-value of 0.436 exceeds the significance level of 0.05. This implies that autocorrelation is not present at lag order 2.

Table 10. Autocorrelation test.

Lag	χ^2	df	Prob > χ^2
1	55.758	36	0.019
2	36.714	36	0.436

4.9. Discussions

These results add to the current conversation about climate change and agricultural output by explaining the factors that affect the agricultural productivity of Somalia in the short term and long term. The empirical findings suggest that in the short run, crop production is positively associated with increases in CO_2 emissions, temperature, rainfall, agricultural land, and employment. For instance, every percentage rise in CO_2 has a corresponding increase of 4.8% in crop productivity, along with temperature and rainfall also having the same impact. This is consistent with the induced innovation [38], that posits that farmers implement traditional adaptation strategies, emphasizing the use of good weather to sustain production.

Based on the long-term results of the study, the Ricardian model of climate change's effects on agriculture [36] does explain why higher levels of CO_2 and average mean temperature (AMT) hurt crop production. More specifically, an increase in $lnCO_2$ by 1% is associated with a drop in crop production by 57%, and likewise, an increase in AMT is associated with more than a 100% reduction in crops produced. This follows studies by Warsame et al. [16,15], who have recorded that exogenous temperature changes have a negative effect on crop production in Somalia, and this is even more pronounced in the long run. In the same manner, Abera et al. [12] suggest that due to climate change stress, maize yields in Ethiopia are estimated to decrease by a shocking 43%.

Rainfall (RF), agricultural land (AL), and labour (L) have a positive correlation in the long run with crop output, supporting the Cobb-Douglas production function [37], that considers these inputs as determinants of agricultural production. Onyeneke et al. [11] corroborate this, asserting that land and labour positively influence Nigeria's agricultural productivity over time. A one percent increase in lnRF results in a 70 percent increase in crop production, as well as an increase in lnAL and lnL production by 12 and 68 percent, respectively. The Harris-Todaro migration model [40] further explains the impact of labour; migration affects the agricultural labour supply due to remittances and investment spending on farming.

5. Conclusion and Policy Implications

Most challenges with agricultural yield in Somalia come from climate change that is straining farming productivity through erratic rainfall, a rise in temperature, and an increase in CO_2 emissions. Defining and implementing appropriate measures to enhance food security and sustainable agriculture requires understanding climate-adaptive strategies based on both short- and long-term dynamics.

The research indicates that in the short term, increases in CO_2, temperature, rainfall, agricultural land, and labour will have a positive impact on crop production. Conversely, in the long term, climate change has led to CO_2 and temperature increases, resulting in negative crop production. In addition, rainfall, agricultural land, and labour positively contribute to the yield gap, which the Somali farming sector desperately needs.

The result underscores the necessity for climate adaptation policies that incorporate both short-term modifications and proactive long-term changes. Proactive measures of investing in climate-resilient agriculture, technological improvements, and better irrigation systems are important to maintain productivity. The study recommends that policymakers must develop targeted policies to assist farmers in reducing the risk of climate change and boosting crop yields in a sustainable manner.

This research faces limitations owing to a lack of data as well as other relevant environmental and socio-economic influences like soil erosion, market competition, and even political violence. Subsequent research should consider additional factors to increase the reliability of climate-agriculture models.

The study suggests exploring how technology impacts the effects of climate change on agriculture. Moreover, socio-economic factors like farmer coping strategies and access to climate-resilient agricultural facilities will enhance the understanding of resilience options in Somalia.

This research adds to the growing body of knowledge about the interaction of climate change and crop production in Somalia. It employs a blend of empirical results with theoretical expectations and calls attention to the need for active intervention measures intended to protect agricultural outputs and food security from fluctuating climate threats.

Author Contributions

Conceptualization, A.Y.S.A. and A.M.N.; investigation, A.Y.S.A.; writing—original draft preparation, A.Y.S.A. and A.M.N.; resources, A.Y.S.A.; writing—review and editing, A.Y.S.A.; supervision, A.Y.S.A.; funding acquisition, A.Y.S.A.; methodology, A.M.N.; software, A.M.N.; formal analysis, A.M.N and A.Y.S.A.; data curation, A.M.N.; visualization, A.M.N. Both authors contributed equally to this work. All authors have read and agreed to the published version of the manuscript.

Funding

There was no outside financing for this work.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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