

Research Article

# Analysis of the Effects of Temperature Changes on Wheat Production in Sub-Saharan Africa

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## Abstract

The effects of climate change, particularly rising global temperatures on global food production, have become a major concern. The main objective of this paper is to assess the effects of temperature changes on wheat production in sub-Saharan Africa between 1980 and 2022 using a Cointegration model based on the ARDL (Autoregressive Distributed Lag) approach in a panel of 37 sub-Saharan African countries. The data used for this purpose come from the FAO database (2023) and the World Bank (WDI, 2023). The results obtained indicate that in the short and long term, temperature changes have a negative effect on wheat production in sub-Saharan Africa. This is reflected in the fact that an increase of 1 °C in temperature leads to a decrease in wheat production in the region, negatively impacting soil conditions. In view of these results, sub-Saharan African countries must collectively and concertedly become aware of the negative effects of temperature changes on wheat production by improving their soil quality; multiply measures to address the multiple problems related to wheat production, especially in rural areas, by supporting agricultural sector stakeholders in developing climate change-resilient strategies.

## Keywords

Temperature Variation, Wheat Production, ARDL in Panel

## 1. Introduction

The African continent is responsible for 9% of the global greenhouse gas emissions, but paradoxically, it is also one of the most vulnerable to climate change in the world. This continent is subject to significant climatic differences, with impressive variations across regions. It (Africa) is crossed by the equator in its center, and therefore has a very hot and humid climate.

Climate change poses a significant threat to agricultural

production in sub-Saharan Africa, a region already vulnerable due to its climatic conditions, poverty, and poor access to technology. Wheat, an important food crop in several countries in the region, is particularly sensitive to climate variations, particularly due to changes in temperature, precipitation, and evapotranspiration. Climate change is “a change in climate that is attributed directly or indirectly to human activity altering the composition of the global atmosphere and that is

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in addition to natural climate variability observed over comparable time periods [24]"

According to the fifth IPCC report, climate change is defined as "a variation in the state of the climate that can be detected by changes in the mean and/or variability of its properties and that persists over a long period, caused by natural processes or persistent anthropogenic changes [39]" climate change is the transformation of the climate that encompasses all the factors that constitute the weather, namely temperatures, precipitation, and winds. In a narrower sense, [14, 54] defines climate change as the average weather, or more rigorously, the statistical description in terms of the mean and variability of relevant quantities over a period ranging from a few months to thousands or millions of years. The classic period for averaging these variables is 30 years, as defined by the World Meteorological Organization.

Climate change manifests itself in many forms: rising global average temperatures, greater variability in temperatures and precipitation, and greater occurrence of extreme events such as drought, floods, and strong winds. The list of climate shocks is growing over the years [48]. The agricultural sector creates jobs, ensures food security, provides raw materials for industry, and generates foreign exchange for the country through foreign trade. Africa finds itself in a paradoxical situation: it is the continent that has had the least impact on the increase in greenhouse gases, responsible for global warming, but it could be the continent most impacted. In recent decades, Africa has experienced significant.

Agriculture plays a crucial role for many developing countries, serving as a key driver of economic growth and a fundamental instrument for food security. In 2019, the work Bank emphasized that agriculture is essential not only for feeding populations but also for supporting the livelihoods of millions, particularly in rural areas [76].

Climate changes in both temperatures and rainfall [38].

Sub-Saharan Africa is a key region for agricultural production, but it is also vulnerable to the impacts of climate change, particularly fluctuations in rainfall and temperature. Wheat production has gradually increased due to improved agricultural technology and investment in the sector. In 2022, total production in the region is estimated at approximately 6.5 million tones [58]. Thus, demand for wheat in countries such as Nigeria and Ethiopia continues to increase, driven by urbanization and dietary changes [30].

Wheat is considered a primary source of human and animal nutrition [68]. Changes in temperature and precipitation are both major determinants of recent trends observed in wheat production in sub-Saharan Africa. Both rising temperatures and, more importantly, declining rainfall have led to production deficits since the 1970s [7].

According to [65], climate change and stagnant public investment in research and development are factors contributing to the slowdown in agricultural productivity. According to [6], climate change affects all sectors of the economy, but particularly the agricultural sector. Climate change in the form of

rising temperatures and rainfall is expected to reduce the total area planted to crop varieties by 2050. The Fifth Assessment Report of the IPCC shows that Africa could experience temperature increases of 1 to 3 °C by 2050. Research indicates that these temperature increases are more severe than the global average.

Hanslow found that changes in temperature and precipitation negatively affect pasture growth [36]. Thus, production in major dairy-producing regions decreases. Yan and Zhang showed that a stronger storm causes greater losses in agricultural production [77]. In West Africa, [12] showed that rainfall and temperatures influence agricultural yields in Mali. Doukpolo reveals that climate change poses a serious threat to agricultural development in western Central African Republic; future rainfall trends indicate a decline in production of up to 20–42%. Molua, examining the effects of changing climate averages on agricultural production in Cameroon, reveals that agriculture is influenced by climatic variables [25, 26]. Bel-lomi, G., in his studies in Southeast Africa, shows that rainfall positively affects agricultural production, while an overall increase in average annual temperature decreases it [8]. The issue of the impact of climate change on agricultural production has already been the subject of numerous scientific studies worldwide, covering several regions and countries [31, 55]. A study on climate scenarios and future agricultural yields predicted that by 2025, climate change will lead to a significant decline in the yields of major crops in sub-Saharan Africa [84]. Most studies estimating the economic costs of climate change use two approaches: the dynamic approach, which incorporates different specializations of growth models into its damage function, is used to analyze the impact of climate change on economic growth, and the enumerative approach, which is applied sector by sector to identify the distinct effects of climate change on the economy. Researchers such as [57, 71, 18, 29, 62, 56], etc.

The impacts of climate change and arable land on food security in Morocco between 1971 and 2017 using a cointegration model based on the ARDL (autoregressive staggered lag) approach. Empirical results show that an increase in precipitation has a positive effect on agricultural GDP, and a 1% increase in temperature has a negative effect on agricultural GDP, with a decrease of 3.14% in the short term and 5% in the long term [28].

In their study [33] on water consumption and agricultural productivity growth in sub-Saharan Africa, they show, using the stochastic production frontier estimation method with random parameters – true (SPF) applied to the agricultural production function, that water endowment as an input to agricultural production has a positive and significant effect on it after correcting for any endogeneity bias problem.

Climate change has had a negative impact on agriculture, which is the main source of livelihoods and national economies in Africa. Agricultural productivity has notably declined by 34% since 1961. This situation is considered the largest decline in agricultural productivity compared to other regions

[53]. Studies show that temperature and precipitation have a significant impact on food production [40–47] and some studies have revealed adverse effects of climate change on agricultural productivity [70, 41].

Zhang and Nearing demonstrated, through a controlled study conducted in the central state of Oklahoma, that a decrease in precipitation has a greater negative impact on crops, while an increase in temperature can be slightly countered by using appropriate crop fertilization [81].

Joshua, Esin and kamal used a method to study the effects of climate change on wheat production in Kansas. They found a positive short-term result between the explanatory variables (temperature and precipitation) and the dependent variable which is wheat production while in the long term; precipitation has a negative effect on wheat production. They concluded that the impacts on global food production due to the effects of climate change, including rising global temperatures and continuous changes in precipitation, have become a significant problem. An increase in temperatures has a positive effect on wheat production in the short term, but it has neither a positive nor a negative effect in the long term. Increased precipitation has a positive short-term effect but a negative long-term effect on wheat production. In summary, the results of the literature review and this empirical study suggest that the overall effect of climate change on agricultural production in developed countries is positive. However, the impact of climate change on agricultural production in developing countries does not seem encouraging. This is probably due to its negative impact on soil conditions and agro-water management [42].

Molua examining the effects of changing climate averages on agricultural production in Cameroon reveals that agriculture is influenced by climatic variables [51]. Blaise Ondua Beyene studied the effect of climate change on agricultural yields in ECCAS countries. He found that these factors (temperature and precipitation) are the main obstacles that significantly slow agricultural yields in the countries concerned. Finally, he demonstrated that rising temperatures and rainfall negatively impact agricultural production [10]. Cloninger has drawn up the same result on agriculture [19].

Dorro Grami and Jalleddine studied the impact of climate change on cereal yields in the northwest region of Tunisia (Beja). The estimation results show that grain yields for varieties are affected by climate change, land area, and technological progress. Thus, these authors demonstrated that an increase in rainfall positively affects grain yield, while an increase in drought frequency can have adverse effects on grain productivity [24]. Shukrillo Abuqayumov, examined climate change and the productivity of major crops in the districts of Punjab, Pakistan. The results show a positive correlation between indicators (temperature and precipitation) and wheat production. Finally, it was shown that wheat productivity is more positively sensitive to precipitation in the long term and that in the short term, the wheat productivity balance converges more quickly, and deviations from average

precipitation are detrimental [66].

In a study in China, [16] investigated the effects of climate change on agricultural production using the Autoscaled Lag Regression (ARSL) approach over the period 1982–2014 to test short-term and long-term dynamics. The results showed that carbon dioxide (CO<sub>2</sub>) positively and significantly affect agricultural production in the short term, while temperature, while precipitation, negatively affects agricultural production in the long term.

Sinwardena and al conducted a study on the effects of climate change on cereal production in India over the period 1966–2011, using FGLS econometric models. They showed that climate change negatively affects cereal production in India [67].

In contrast, [27] concluded that precipitation and temperature variables positively affect cereal production over the period 1961–2013 in Turkey. The authors used Autoregressive Lag Scaled or Distributed Regression models.

In this regard, results by [21] show that climate change in the same countries around the world does not affect wheat production in Pakistan. These results contradict the results of [83], who conducted the same studies using the same method and the same problem, covering the period 1970–2014 in China. The latter incorporated technological progress as an additional explanatory variable for wheat yields. The results showed that technological progress, particularly agricultural machinery and fertilizer consumption, significantly increases wheat yield, unlike climatic variables, particularly precipitation and temperature. It follows that precipitation positively affects agricultural production in the short term, while temperature has detrimental effects on agricultural production in the long term.

Ahram et al analyzed the effects of climate change on cereal production over a period of 1971–2014 in Pakistan, using Johnston cointegration tests in ARDL. The results showed that climate change, particularly temperature and precipitation variables, have a negative effect on cereal crops in the short and long term [1].

As part of the problem of the effects of climate change, [61] and [82] analyzed the effects of temperatures and water availability on crops using different methods and experiments. They reported that rising temperatures and water variability threaten crop productivity. Despite the different methods applied to their breeding, their results revealed that rising temperatures expose agricultural production at global, national, and local levels. In addition to another study conducted in Turkey by [15], using the Johansen Cointegration test in ARDL, found a relationship between CO<sub>2</sub> dioxide and temperature, on the one hand, and cereal yield, on the other; while the author found a positive relationship between precipitation and cereal yield in both the short and long term.

In sub-Saharan Africa, wheat production is dominated by subsistence farmers, and its productivity is still very low, partly due to the availability, accessibility, and affordability of inputs such as irrigation fertilizers, pesticides, and agricultural

machinery [4].

The scientific debate on the magnitude of the effects and the nature of the relationship between climate change and agricultural yield remains ongoing and appears to be ongoing. Our work provides elements of a response aimed at fueling the scientific debate on the existence of climate change and its effects on wheat production, placing sub-Saharan Africa at the center of the debate. To address this gap, we aim to answer the question: What is the effect of temperature changes on wheat production in sub-Saharan Africa?

Sub-Saharan Africa is vulnerable to the effects of climate change, particularly temperature variations. The region faces major agricultural challenges, and wheat, although not traditionally cultivated in many parts of the region, is becoming increasingly important as a staple crop. The impact of climate change on wheat production in sub-Saharan Africa is a growing topic of research, given the strategic importance of this crop in the region's food security. The objective of this work is to assess the effect of annual temperature changes on wheat production in sub-Saharan Africa. Finally, our article is structured around a literature review (I); a methodology (II); and an empirical validation of the models; and a recommendation (II).

## 2. Literature Review

Every plant has requirements regarding the climate in which it grows. These translate into a number of climatic needs: the need for solar radiation intercepted by the foliage, and thermal requirements for its development. This is why temperatures are a limiting factor for agricultural yield [45].

Theoretical studies demonstrate that climate change through temperatures affects agricultural yield. Studies conducted over the past several years have shown diverse impacts of temperatures on agricultural yield. For example, work conducted by [37] in Ghana using household surveys shows that rising temperatures reduce agricultural production. They demonstrate that temperature variability is one of the current challenges to increasing agricultural yield.

Boko et al. analyzed climate change adaptation strategies in agriculture in West Africa, including wheat cultivation. They suggested the adoption of wheat varieties more resistant to heat and drought, as well as improved agricultural practices such as irrigation and improved soil management to mitigate the effects of climate change [13].

Miller et al explored adaptation approaches for agriculture in sub-Saharan Africa, including the implementation of agricultural technologies and agricultural policies to strengthen the resilience of cereal farms to the impacts of climate change. Improved irrigation systems and the use of disease- and drought-resistant seeds were proposed [50].

In another study, [2, 26] assessed the effects of climate change (maximum temperature, minimum temperature, precipitation, relative humidity, and sunshine) on major crops (wheat, rice, maize, and sugarcane) in Pakistan. Using time

series data from 1989 to 2015, they found that maximum temperature negatively affects wheat production, while minimum temperature has a positive and significant effect on all crops.

Dorro Grami and Jalleleddine Ben Rejed, in their research entitled "The impact of climate change on cereal yields in the northwest region of Tunisia (Beja), found, depending on the model used, a marginally significant relationship between the dependent variable and the explanatory variable (temperature T), confirming that temperature negatively affects wheat production. The second-order coefficients of the temperature variables are negative, confirming that temperature negatively affects cereal yield (wheat) [24]. Joshua and al, in their research, examined climate change on wheat production in Kansas over the period 1949 to 2014. The results demonstrate that temperature has a positive effect on wheat production in the short term [42].

Ali Chebil, Nadhem Mtimet, and Hassen Tizaoui in their research entitled: Impact of Climate Change on Cereal Crop Productivity in the Beja Region (Tunisia). The analysis period is from 1980 to 2009. The estimation results show that the coefficients of the variables: the average minimum temperature for the months of November-December (TND) and the average maximum temperature variation for the months of March-April (TMA) are positive and insignificant on durum and soft wheat production in the Beja region (Tunisia) [3].

Variations in climatic conditions can have a significant impact on cereal crop yields. Schlenker and Robet identified a critical temperature threshold favorable to cereal production. According to these authors, only temperatures above 290C and 300C can positively influence cereal yields [64]. Ritchie and Nesmith found a maximum threshold of 340C beyond which temperature will have a detrimental effect on plant yields [63].

High temperatures reduce plant growth by affecting net shoot assimilation rates and therefore total plant dry weight. In many crop species, the effects of high-temperature stress are more significant on production development than on vegetative growth, and the sudden decline in yield with temperature is primarily associated with sterility [74]. Blaisse Ondua Beyene examines the effects of climate change on agricultural yields in ECCAS countries. He used a Generally Least Squares (OLS) method. The data used in this model are panel data for the period 2003-2011. According to the results, temperature has a negative effect on agricultural yields in ECCAS countries [11].

Dandonougbo Yevessé in his research entitled: Economic Analysis of the Effects of Variation in Temperature and Precipitation on Cereal Production in Togo. The results show the existence of a nonlinear relationship between maize and rice crop yields and climatic variables. In the case of rice, this means that an increase in average temperature during the rainy season increases agricultural yield up to a given threshold, and beyond this threshold, any increase in temperature has a negative effect on rice agricultural yields. How-

ever, during the dry season, the opposite effect is observed, with any increase in temperature leading to a decrease in maize yields [22]. The same results are observed for maize, but its coefficients are not significant. This nonlinear relationship is verified in most studies, particularly in Burkina Faso [59] and Niger [34].

In a recent study in China, [16] conducted investigations into the effects of climate change on agricultural production using the Autoregression with Scaled Lags (ARD) approach covering the period 1982–2014 to test short-term and long-term dynamics. The results showed that carbon dioxide (CO<sub>2</sub>) positively and significantly affects agricultural production in the short term, while temperature exerts a negative effect on agricultural production in the long term.

Sinwardena et al conducted a study on the effects of climate change on cereal production in India over a period of 1966–2011, using FGLS econometric models. The authors showed that temperature negatively affects cereal production in India [67].

Zhan et al analyzed the effects of climate change on cereal production over a period of 1971–2014 in Pakistan; using Johansen Cointegration tests in ARDL. The results showed that climate change, particularly temperature variability, has a negative effect on cereal cultivation in the short and long term [80].

Shukillo Abduqayumov, in his article entitled "Impact of climate change on the productivity of major crops in the districts of Punjab over the period 1970 to 2010. He found a positive correlation between temperature and wheat production [66].

Joshua C. and al, in their research, examined climate change on wheat production in Kansas over the period 1949 to 2014. The results demonstrate that temperature has a positive effect on wheat production in the short term [42].

Hassan and Nhemachena demonstrated that rising temperatures could reduce wheat production in sub-Saharan Africa. Their study modeled the effects of climate change on agriculture in Africa, focusing on the vulnerability of wheat cultivation, particularly due to temperature increases during the growing season [35].

Tiruneh et al studied the impact of global warming on wheat production in dry and semi-arid areas of East Africa. They found that temperature increases beyond certain limits can reduce yield, particularly during flowering and grain filling, which are phases sensitive to high temperatures [72]. In addition, another recent study conducted in Turkey by [15] using the Johanssen cointegration test in ARDL found a positive relationship between CO<sub>2</sub> dioxide and temperature on the one hand and cereal yield on the other.

Bensbahou, A. and al studied the impact of climate change on agricultural production: the case of the Sous-Massa region. The estimation results showed that the value associated with the likelihood ratio test in the SDM model (the optimal model) is relatively higher compared to that corresponding to the same test in the SAR model. In addition, the variable (Tem-

perature in °C) displays a positive sign. This suggests that the expected increase and decrease in temperature will reduce the net productivity of citrus fruits in the Sous-Massa region [9].

Diouf et al. used climate models to predict wheat yields in sub-Saharan Africa under a climate change scenario. They showed that if current warming and precipitation changes continue, wheat yields could decline significantly in regions such as Senegal and Morocco [23].

Ashraf et al. Demonstrated, through modeling studies, that increasing average temperatures and reducing precipitation would increase the risk of heat stress and water deficits, thereby reducing wheat productivity [5].

### 3. Methodology

#### 3.1. Methodological Framework of the Analysis

All scientific knowledge is formalized using a precise methodology so that the plausibility of the results can be demonstrated by referring to experiments and logical arguments. This means that scientific knowledge is distinguished from everyday knowledge by the rigor of the methodological rules to be applied during the formalization process [52].

In this subsection, we will specify the analysis model, present the variables to be used, and present the data source and estimation method. Our study is conducted in Sub-Saharan Africa. This economic zone has an area of approximately 22, 431, 000 km<sup>2</sup> and a population of approximately 1, 022, 664. This population represents 48 countries.

*Choice of Variables and Expected Economic Signs*

##### 3.1.1. The Explained Variables

*Wheat Production (PBLE)*

Agriculture contributes to the food security of populations, creates numerous jobs, provides raw materials for industry, and improves the population's income. The expected sign of this parameter is positive [44].

##### 3.1.2. Explanatory Variables

1) Cultivated Area (CA)

Land is a very important production factor according to economic theory. It can even be considered the foundation of agriculture. Thus, cultivated land, which is land dedicated to agriculture, generally has a positive impact on agricultural production and therefore economic growth. However, the strong growth in agricultural production in SSA is mainly explained by the expansion of cultivated areas and the intensification of cropping systems, and not by large-scale improvements in productivity [55, 14]. It is expressed in square kilometers of agricultural land. The expected sign of this parameter is positive.

2) Population growth rate (POP).

According to the [69], population growth reduces per capita capital and therefore per capita output in a country. Some

research shows that it stimulates economic growth. Others, however, assert that population growth can have a negative or positive influence, depending on the case. However, studies applied to African countries generally find a negative effect of the population growth rate on the real growth rate of GDP per capita. The sign of the coefficient for this variable should be negative.

### 3) Temperature variations (TEMP).

To measure the effect of climate, the maximum reported temperature can be used. Maximum temperature is important because all crop functions depend on maximum temperature for crops to develop their growth. At maximum temperature, many crops can grow rapidly, but their productivity may be reduced if their higher growth period is not supplemented with adequate water and fertilizer supplies [73]. As indicated above, temperature (TEMP) is the climate change variable, and its coefficient is the subject of this study. If the TEMP coefficient is negative and statistically significant, we can say that global warming has a negative effect on wheat production. If it is positive and statistically significant, we can say that global warming has a positive effect on wheat production. The expected sign of this parameter is negative.

### 4) Fertilizer Consumption (CENG).

Fertilizer is essentially a chemical or natural substance used on land to increase its fertility. The most important types of fertilizers are mixtures of carbon, hydrogen, and oxygen. Land that has been frequently cultivated generally becomes infertile over time and exhibits a decline in productivity. The sign of the coefficient for this variable is expected to be positive.

### 5) Rural Labor Force

Since SSA is generally considered a land-rich region, the continued expansion of cultivated areas over the coming decade may not appear to be a problem. However, rural areas in SSA are highly heterogeneous, and although a large proportion of land remains unused or underutilized, a considerable proportion of the rural population lives in family farming areas that are densely populated and land-scarce [78]. The agricultural sector plays a central role in employment in SSA, employing more than half of the total workforce. While its importance to the rural population is well established, recent

studies suggest that agriculture is also the primary source of income for 10% to 25% of urban households. National census data indicate that the number of people employed primarily in agriculture has been increasing over time [79]. The coefficient sign for this variable is expected to be positive.

### 6) Trade in Goods

Crossman and Helpman demonstrate that openness increases domestic imports of goods and services that incorporate new technologies. Through learning by doing and technology transfer, the country experiences technological progress, its production becomes more efficient, and its productivity increases. The sign of the coefficient for this variable should be positive [20].

### 7) Inflation

Inflation rate measured by the consumer price index (in %). Rising prices reduce purchasing power and increase poverty. This has the effect of increasing income inequality. The sign of the coefficient for this variable should be negative.

## 3.2. Model Specification and Study Data

### 3.2.1. Model Specification

The relationship between wheat production, temperature variations, fertilizer consumption, agricultural land, total population, commodity trade, inflation, and rural population can be written as follows:

$$PBLE = f(TEMP, CENG, TAGR, POP, COM, INF, PRUALE)(1)$$

Before testing the above model, unit root tests must first be performed on each variable to verify stationarity. We will attempt to verify the long-term and short-term relationships between the variable to be explained (wheat production) and the explanatory variable (temperature). Thus, we adopt a time-lag model [46]. The model specification (ARDL) of equation (1) is expressed as an unrestricted error correction model (UECM) to test for Cointegration between the study variables:

$$PBLE = f(TEMP, CENG, TAGR, POP, COM, INF, PRUALE). \Delta \ln PBLE_{it} = \varphi_0 + \sum_{pi=1} \varphi_1 \Delta \ln PBLE_{it-1} + \sum_{pi=0} \varphi_2 \Delta \ln TEMP_{t-1} + \sum_{pi=0} \varphi_3 \Delta \ln CENG_{t-1} + \sum_{pi=0} \varphi_4 \Delta \ln TAGR_{t-1} + \sum_{pi=0} \varphi_5 \Delta \ln POP_{t-1} + \sum_{pi=0} \varphi_6 \Delta \ln COM_{t-1} + \sum_{pi=0} \varphi_7 \Delta \ln INF_{t-1} + \sum_{pi=0} \varphi_8 \Delta \ln PRUALE_{t-1} + \beta_1 \ln PBLE_{t-1} + \beta_2 TEMP_{t-1} + \beta_3 \ln CENG_{t-1} + \beta_4 \ln TAGR_{t-1} + \beta_5 \ln POP_{t-1} + \beta_6 \ln COM_{t-1} + \beta_7 \ln INF_{t-1} + \beta_8 \ln PRUALE_{t-1} + \mu t \quad (2)$$

Once the cointegration is established, the long relationship is estimated using the conditional ARDL model specified as follows:

$$\ln PBLE_{it} = \varphi_0 + \beta_1 \ln TEMP_{t-1} + \beta_2 \ln CENG_{t-1} + \beta_3 \ln TAGR_{t-1} + \beta_4 \ln POP_{t-1} + \beta_5 \ln COM_{t-1} + \beta_6 \ln INF_{t-1} + \beta_7 \ln PRUALE_{t-1} + \mu t \quad (3)$$

Thus the short-term dynamic relationship is estimated using the error correction model as follows:

$$\Delta \ln \text{PBLE}_{it} = \varphi_0 + \sum_{pi=1} \varphi_1 \Delta \ln \text{PBLE}_{it-1} + \sum_{i=0} p \varphi_2 \Delta \ln \text{TEMP}_{t-1} + \sum_{pi=0} \varphi_3 \Delta \ln \text{CENG}_{t-1} + \sum_{pi=0} \varphi_4 \Delta \ln \text{TAGR}_{t-1} + \sum_{pi=0} \varphi_5 \Delta \ln \text{POP}_{t-1} + \sum_{pi=0} \varphi_6 \Delta \ln \text{COM}_{t-1} + \sum_{pi=0} \varphi_7 \Delta \ln \text{INF}_{t-1} + \sum_{pi=0} \varphi_8 \Delta \ln \text{PRURALE}_{t-1} + \text{ICE}_{t-1} + \mu_t \quad (4)$$

**Table 1.** Meaning of model variables and parameters, unit of measurement, and predicted signs.

| Variables/Parameters | Meanings               | Predicted Signs |
|----------------------|------------------------|-----------------|
| PBLE                 | Wheat Production       | (+)             |
| TEMP                 | Temperature Variation  | (-) ou (+)      |
| CENG                 | Fertilizer Consumption | (+)             |
| TAGR                 | Agricultural Land      | (+)             |
| POP                  | Population Growth Rate | (+) ou (-)      |
| COM                  | Merchandise Trade      | (+)             |
| INF                  | Inflation              | (-)             |
| PRURALE              | Rural Population       | (+)             |
| $\text{ICE}_{t-1}$   | Error Correction Index | -               |
| $\varphi_0$          | Constant               | +               |
| $\mu_t$              | Error Term             | +/-             |
| $\Delta$             | Variation              | /               |
| $\text{Ln}$          | Natural Logarithm      | /               |
| $p$                  |                        | /               |

Source: Author

### 3.2.2. Data Processing Tests

The steps we will follow for the estimation are as follows:

- 1) Specification tests from [46]: Panel Unit Root Test (MW)
- 2) Interdependence test of panel variables: Weak Cross-sectional Dependence (WCsD)
- 3) Presentation of descriptive statistics
- 4) Development of the correlation matrix

### 3.2.3. Study Data

To determine the effect of temperature variations on wheat production, the annual data used in our study are secondary data from the [32] and World Bank [75] databases for the period 1980 to 2022 from 37 countries, 37 of which are wheat producers or less, in Sub-Saharan Africa. The sample covers the period 1980–2022 due to data availability. Given that the number of years per country exceeds 20, this study will therefore use a panel cointegration approach [46, 60].

For practical reasons, our empirical verification requires the use of Excel 2016 software, which allowed us to create our database, and Stata 14 software for our various estima-

tions.

## 4. Empirical Validation of the Model: Results and Economic Policy Recommendations

After interpreting and analyzing our estimates, we will first process our data using STATA 14, EVIEWS, and EXCEL software to present the various tests of the preliminary results (Weak Cross-sectional Dependence and CADF stationarity tests).

### 4.1. Results of the Preliminary Tests

#### The WCsD Interdependence Test

The results of the WCsD interdependence test are contained in the following table:

The results presented in Table 2 below lead us to accept the null hypothesis of interdependence and confirm the presence of interdependence between the variables in our panel (those with a p-value <1%). Indeed, there is interdependence for all variables: wheat production (PBLE), temperature variations (TEMP), fertilizer consumption (CENG), agricultural land (TAG), population growth rate (POP), merchandise trade (COM), inflation (INF), and rural population (PRULAL), since their p-values are less than 1%. The presence of interdependence among the variables is certainly due to phenomena in the region. Thus, an extreme phenomenon can destroy wheat production in the region. The result of this interdependence test is useful because it will allow us to choose the appropriate unit root test for our variables.

**Table 2.** Test d'interdépendance WCsD.

| Variables | Test (CD)         | Test statistique | p-value |
|-----------|-------------------|------------------|---------|
| PBLELOG   | Pesaran WCsD test | 77.101           | 0.000   |
| TEMP      | Pesaran WCsD test | 61.782           | 0.000   |
| CENG      | Pesaran WCsD test | 100.008          | 0.000   |
| TAGR      | Pesaran WCsD test | 50.872           | 0.000   |
| POP       | Pesaran WCsD test | 155.892          | 0.000   |
| COM       | Pesaran WCsD test | 17.219           | 0.000   |
| INF       | Pesaran WCsD test | 16.667           | 0.000   |
| PRURALLOG | Pesaran WCsD test | 127.981          | 0.000   |

Source: Author, processing performed on Stata 14.

## 4.2. Stationarity Test Results

### 4.2.1. «(Mandala and Wu, 1999)» Stationarity Test: Panel Unit Root Test (MW)

The results of the stationarity test developed by [46] are shown in the following table:

**Table 3.** MW Stationarity Test.

| Variables | chi_sq  | P-value | Order of integration |
|-----------|---------|---------|----------------------|
| PBLELOG   | 194.946 | 0.000   | I(1)                 |
| TEMP      | 457.158 | 0.000   | I(1)                 |
| CENG      | 126.332 | 0.000   | I(1)                 |
| TAGRLOG   | 167.826 | 0.000   | I(1)                 |
| POPLOG    | 626.762 | 0.000   | I(1)                 |

| Variables | chi_sq  | P-value | Order of integration |
|-----------|---------|---------|----------------------|
| COM       | 162.353 | 0.000   | I(1)                 |
| INF       | 785.280 | 0.000   | I(1)                 |
| PRURALLOG | 870.586 | 0.000   | I(1)                 |

Source: Author, processing performed using Stata version 14.

According to the results of this test, all variables are stationary at the 1% threshold in first difference. The table shows that the null hypothesis of the presence of a unit roots among our variables is rejected, meaning that all our variables are stationary. This result also demonstrates that our variables have deterministic and stochastic characteristics that are stable over time, which can already help us obtain unbiased estimation results.

We then present the descriptive statistics for the variables in our model.

### 4.2.2. Presentation of Descriptive Statistics

**Table 4.** Descriptive Statistics.

| Variable  | Obs  | Mean   | Std. Dev. | Min     | Max       |
|-----------|------|--------|-----------|---------|-----------|
| PBLELOG   | 1578 | 13.531 | 1.787     | 8.702   | 17.269    |
| TEMP      | 1591 | .655   | .493      | -.83    | 2.209     |
| CENG      | 1589 | 12.883 | 18.494    | 0       | 130.075   |
| TAGRLOG   | 1541 | 13.507 | 1.632     | 8.868   | 16.781    |
| POPLOG    | 1591 | 15.971 | 1.257     | 13.302  | 19.202    |
| COM       | 1591 | 47.419 | 30.929    | 0       | 187.595   |
| INF       | 1591 | 44.512 | 699.66    | -29.173 | 26765.858 |
| PRURALLOG | 1591 | 15.72  | 1.668     | 12.307  | 21.886    |

Source: Author

Table 4 provides descriptive statistics for the various variables used in this study. Observation of the table shows that the logarithm of wheat production has a mean of 13.53 with a low dispersion that varies between 8.702 and 17.269 over the period 1980 to 2022. This production is still very low. This is likely due to climatic conditions marked by rising extreme temperatures and poor agricultural policy. However, the logarithm of wheat production is characterized by low variability over the period from 1980 to 2022 (between 8,702 kg/ha and 17,229 kg/ha), which shows an uneven distribution of productivity in the wheat sector in sub-Saharan Africa. This inequality is confirmed by the distribution of the land en-

dowment used, which varies between 8,869 ha and 16,781 ha; the average value is 13,507 ha over the study period.

Regarding temperature variation, the average is 1.65 °C, demonstrating that global warming has not yet reached critical thresholds in the region. In addition, the average values of temperature variations fluctuate between -1.83 °C and 2,209 °C. However, depending on the agro-climatic zones, significant regional variations can be observed. Indeed, Temperature variations followed a low trend in the early 1980s, reaching their lowest values starting in 2000 and continuing to decline.

Fertilizer consumption averages 12.83%, which explains

the low use of fertilizers for wheat production in sub-Saharan Africa. The logarithm of the population growth rate averages 15.97, with a narrow dispersion that varies between 13.30 and 19.20, meaning that the population of sub-Saharan Africa almost tripled between 1980 and 2022 (in just 42 years). Merchandise trade averages 47.41, which is still very low and could explain the low trade in agricultural products in the region, with low inflation, averaging 44.512, which explains the decline in market prices. Finally, the logarithm of the rural population averages 15.72, which explains the rural popula-

tion's nearly tripled increase between 1980 and 2022 (in just 42 years), with a low dispersion that varies between 12, 307 and 21, 886, indicating low participation in wheat production.

After presenting the various descriptive statistics, we then present the correlation matrix.

#### 4.2.3. Development of the Correlation Matrix

The correlation matrix is presented in the following table:

**Table 5.** Correlation matrix.

|           | PBLELOG   | TEMP     | CENG     | TAGRLOG   | POPLOG    | COM      | INF    | PRURAL-LOG |
|-----------|-----------|----------|----------|-----------|-----------|----------|--------|------------|
| PBLELOG   | 1         |          |          |           |           |          |        |            |
| TEMP      | 0.0299    | 1        |          |           |           |          |        |            |
| CENG      | 0.174***  | 0.0387   | 1        |           |           |          |        |            |
| TAGRLOG   | 0.951***  | -0.00199 | 0.0616*  | 1         |           |          |        |            |
| POPLOG    | 0.886***  | 0.00675  | 0.0640*  | 0.863***  | 1         |          |        |            |
| COM       | -0.449*** | 0.0785** | 0.255*** | -0.431*** | -0.458*** | 1        |        |            |
| INF       | 0.0150    | -0.0467  | -0.0302  | 0.0268    | 0.0516*   | -0.00529 | 1      |            |
| PRURALLOG | 0.594***  | -0.0391  | 0.00400  | 0.604***  | 0.633***  | -0.0489  | 0.0335 | 1          |

Source: Author, processing performed using Stata version 14.  
t statistics in parentheses \*p< 0.05, \*\*p< 0.01, \*\*\*p< 0.001

The correlation matrix presented above shows that there are positive and negative correlations between the explanatory variables and the variable to be explained.

Indeed, we observe that the correlation coefficient between wheat production and temperature variation is 0.0299, which means that there is a positive but weak relationship between these two variables.

The table also shows that the variables fertilizer consumption, population growth rate, and merchandise trade have a positive and insignificant relationship, with the exception of the merchandise trade variable, which is positive and significant at the 1% level with temperature variation. Conversely, the variables agricultural land, inflation, and rural population have a negative and insignificant relationship with temperature variation.

Furthermore, the matrix shows that the wheat production variable is highly correlated, positive and significant at 1% with the variables (fertilizer consumption, agricultural land, and population growth rate), with the exception of the inflation variable, which is not significant. In contrast, the mer-

chandise trade variable has a negative and significant relationship at 1% with wheat production.

To verify the absence of a multicollinearity problem between the independent variables, we calculated the correlation coefficients between these variables. Examining the correlation matrix in Table 5 shows that all the correlation coefficients are significantly lower than 0.7 (with the exception of the correlation coefficient between the population growth rate and agricultural land), which is the limit drawn by [6] at which we begin to have a serious multicollinearity problem. In this regard, we can conclude that a multicollinearity problem is absent. After presenting the correlation matrix, we proceed to interpret and analyze the results of the analysis model estimation.

#### 4.2.4. Interpretation and Analysis of Model Estimation Results

These results are presented in the following table.

**Table 6.** Explanatory models of temperature variations on wheat production in sub-Saharan Africa.

| ARDL sur des données en Panel | Equation 1<br>PBLELOG | Equation 2<br>PBLELOG | Equation 3<br>PBLELOG | Equation 4<br>PBLELOG |
|-------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Short run coeff               |                       |                       |                       |                       |
| L.PBLELOG                     | 0.174** (2.63)        | 0.314*** (5.01)       | 0.198*** (3.73)       | 0.255*** (4.98)       |
| TEMP                          | -0.0896* (-2.30)      | -0.170*** (-3.62)     | -                     | -                     |
| COM                           | -0.00226 (-1.67)      | -                     | -                     | -                     |
| TAGRLOG                       | 1.046*** (7.14)       | -                     | 0.899*** (12.29)      | 1.008*** (9.55)       |
| L.TEMP                        | 0.00162 (0.04)        | -0.00636 (-0.11)      | -                     | -                     |
| L.TAGRLOG                     | -0.131 (-1.31)        | -                     | -0.163** (-2.85)      | -0.255** (-2.97)      |
| L.COM                         | 0.00105 (0.95)        | -                     | -                     | -                     |
| CENG                          |                       | -0.00118 (-0.11)      |                       | -0.00382 (-0.87)      |
| INF                           | -                     | 0.000419 (0.21)       | -                     | -                     |
| L.CENG                        | -                     | 0.0145 (1.86)         | -                     | 0.00809 (1.86)        |
| L.INF                         | -                     | 0.000484 (0.21)       | -                     | -                     |
| PRURALLOG                     | -                     | -                     | 5.413 (0.60)          | -                     |
| L.PRURALLOG                   | -                     | -                     | -4.918 (-0.56)        | -                     |
| Long run coeff                |                       |                       |                       |                       |
| lr_COM                        | 0.000858 (0.39)       | -                     | -                     | -                     |
| lr_PBLELOG                    | -0.826*** (-12.45)    | -0.686*** (-10.96)    | -0.802*** (-15.14)    | -0.745*** (-14.54)    |
| lr_TAGRLOG                    | 1.414*** (4.94)       |                       | 1.005*** (9.94)       | 1.036*** (8.76)       |
| lr_TEMP                       | -0.0761 (-0.75)       | -1.417 (-1.75)        |                       |                       |
| lr_CENG                       | -                     | -0.0221 (-0.52)       | -                     | 0.0108 (1.38)         |
| lr_INF                        | -                     | -0.0846 (-0.85)       | -                     | -                     |
| lr_PRURALLOG                  | -                     | -                     | 1.113 (1.62)          | -                     |
| N                             | 1393                  | 1423                  | 1393                  | 1386                  |
| Groups                        | 37                    | 37                    | 37                    | 37                    |
| CD p value                    | 0.4246                | 0.4547                | 0.0171                | 0.0238                |

t statistics in parentheses: \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

Source: Author

*Testing Hypothesis 1: Effect of temperature variations on wheat production in sub-Saharan Africa over the period 1980 to 2022.*

#### Short-term estimates

Regarding the empirical evaluation, Table 6 reports the results of the estimates of the effect of temperature variations on wheat production in sub-Saharan Africa.

In columns (1), (2), (3), and (4) of Table 6, the coefficient associated with the wheat production variable (L. PBLELOG) has a positive sign and is significant at the 1% and 5% levels. This variable has the economically expected sign. These results suggest that producers do indeed respond to changes in

wheat prices (price increases) by modifying wheat production (cultivated area) in the short term. The estimated coefficient for wheat production implies that a 1% increase in wheat production will increase the agricultural growth rate and also allow sub-Saharan Africa to increase its production.

The coefficient for temperature variations (TEMP) is negative and significant at the 1% and 10% levels in columns (1) and (2). The sign of this variable is unexpected. However, by introducing a control variable into the model, namely the allocation of land used for agriculture, the estimation results improve. Indeed, the coefficients associated with temperature variations are all negative and significant (columns 1 and 2,

Table 6).

This shows that a 1 °C increase in temperature during the same period promotes the appearance of plant diseases and, consequently, would lead to a decrease in wheat production of 2.3 kg/ha and 3.62 kg/ha, all other things being equal. To address this shortcoming, farmers in the region (sub-Saharan Africa) could use varieties tolerant to these diseases. Furthermore, producers in this region could resort to supplemental irrigation during critical periods. This suggests that climate change, in terms of decreasing temperatures, has a negative and statistically significant effect on wheat production in sub-Saharan Africa.

Finally, this hypothesis is consistent with those of [24, 43] in their research, which found that temperature variation negatively affects wheat production. This result leads us to validate our hypothesis regarding a negative effect of temperature variation on wheat production in sub-Saharan Africa.

In the short term, the associated coefficient of the agricultural land variable (TAGRLOG) is positive and statistically significant at the 1% level in columns (1), (3), and (4). This result is expected. A 1% increase in agricultural land area results in a 7.14% and 12.29% increase in wheat production. All other things being equal, we can say that the arable land is favorable for wheat production. This confirms the theory.

Furthermore, the estimation result in column (1) shows that the coefficient of the merchandise trade (COM) variable is negative and insignificant. This result is not expected, as merchandise trade promotes trade between nations. For [49], the opportunities offered by cross-border trade constitute a factor in regional economic development as a whole. Any 1% increase in merchandise trade will lead to a 1.67% decrease in wheat production. Finally, we can say that merchandise trade negatively impacts wheat production and does not promote trade in agricultural products, particularly wheat in sub-Saharan Africa, meaning that wheat trade is virtually nonexistent compared to other agricultural products. Estimating equation (2) shows that the coefficient of the inflation variable (INF) is positive and insignificant. This result is expected. This means that a 1% increase in inflation leads, all other things being equal, to a 0.21% increase in wheat production. This price increase encourages agricultural producers to produce more.

Then, the coefficient associated with the fertilizer consumption variable (CENG) is positive and insignificant in columns (2) and (4). This result is expected. These coefficients imply that a 1% increase in fertilizer use will increase wheat productivity by 0.0145% and 0.0081%. This variable (fertilizer consumption) fertilizes the soil and increases wheat production in the region.

Finally, the coefficient of the rural population variable (PRURALLOG) is positive and insignificant in column (3). This result is expected. Every 1% increase in the labor force will lead to a 5.413% increase in wheat production. Since the variable (PRURALOG) is insignificant, this means that when the level of the rural population increases, this results in an

increase in agricultural activity the following year. This can be justified by the fact that agricultural activity in sub-Saharan Africa is considered a rural activity where the majority of the population practices more wheat cultivation.

#### *Long-term Estimates*

The results of the long-term estimation show that the coefficient associated with the wheat production variable (lr\_PBLELOG) is negative and significant at the 1% level in all columns (1), (2), (3), and (4). This variable has an economically unexpected sign. The estimated coefficient for wheat production implies that a 1% decline in wheat production will decrease the long-term agricultural growth rate.

The associated coefficient for temperature variation is negative and insignificant in columns (1) and (2). This result is unexpected. Indeed, a 1 °C increase in temperature leads to a decrease in wheat productivity of 0.75% and 1.75%, all other things being equal. This suggests that climate change, in terms of decreasing temperatures, negatively impacts wheat production and does not favor wheat growth. According to [73], at maximum temperatures, many crops can grow rapidly, but their productivity can be reduced. This hypothesis has been confirmed by authors such as [3], who showed that temperature variation negatively affects wheat production. The result found leads us to validate our hypothesis regarding a negative effect of temperature variation on wheat production in sub-Saharan Africa.

The table of estimates for the agricultural land variable (lr\_TAGRLOG) shows that all the coefficients of the variable estimates are negative and significant in columns (1), (3), and (4). This result is not expected. However, land is a very important production factor and generally has a positive effect on agricultural production according to economic theory, as production increases with cultivated area. This is probably due to its negative impact on soil conditions. These coefficients imply that a 1% increase in cultivated area results in a decrease in wheat production of 4.94%, 9.94%, and 8.76%, all other things being equal.

The coefficient of the estimate in column (1) shows that the merchandise trade variable (lr\_COM) is positive and insignificant in the long run. This result is expected. Every 1% increase in merchandise trade leads to a 0.39% increase in wheat production. Finally, we can say that merchandise trade has a positive impact on wheat production and promotes wheat trade in sub-Saharan Africa in the long run.

The coefficient of the rural population variable (lr\_PRURALLOG) is positive and insignificant. This result is expected. Any 1% increase in the labor force will lead to a 1.62% increase in wheat production. Since the variable (lr\_PRURALLOG) is positive, this means that the rural population (producers) is growing wheat extensively in sub-Saharan Africa in the long term.

Regarding the inflation variable (lr\_INF), the coefficient of this variable is negative and insignificant in column (2). This result is expected. This means that an increase in the general price level (inflation) leads, all other things being equal, to a

decrease of 0.85 units in wheat production. This means that when the general price level decreases, it results in a decline in wheat production because supply does not encourage producers to produce more in the long term. Finally, the coefficient of the fertilizer consumption variable ( $lr\_CENG$ ) in column (2) is negative and insignificant in column (2). This result is not expected. Because the use of fertilizers allows the rapid growth of the plant. Fertilizer is essentially a chemical or natural substance used on the land to increase its fertility. Any increase in fertilizer of 1% will lead to a decrease in wheat productivity to 0.52%. Column (4) shows us that the associated coefficient of the inflation variable ( $lr\_CENG$ ) is positive and insignificant. This result is expected. This means that an increase in fertilizer use of 1% leads, all other things being equal, to an increase of one unit of 1.38% in wheat production in the long term. Sub-Saharan African countries should disseminate the necessary knowledge and techniques through awareness programs for wheat producers on the benefits and consequences of using fertilizers on wheat crops, and finally, explain to rural populations how and when fertilizers should be applied.

#### *Economic Policy Recommendations*

Given the results of our study, they entrusted us with proposing economic policy recommendations to the leaders of sub-Saharan Africa. In the short term, temperature variations have a negative and significant effect on wheat production in sub-Saharan Africa. In the long term, temperature variations have a negative and insignificant effect on wheat production in sub-Saharan Africa. We can therefore draw several lessons from these results and make proposals for economic policy direction. This policy essentially aims to improve the productive performance of the wheat sector in sub-Saharan Africa, and to this end, the following recommendations can be made:

- 1) Better manage irrigation systems;
- 2) Follow the steps of developed countries in wheat production;
- 3) Improve soil quality;
- 4) Increase efforts to address the multiple problems associated with wheat production, especially in rural areas; • Support agricultural sector stakeholders in developing climate change adaptation strategies;
- 5) Encourage research and development of wheat varieties adapted to new climate conditions;
- 6) Promote sustainable agricultural practices that include crop diversification and the use of soil conservation techniques.

## 5. Conclusion

Climate variability is a global phenomenon affecting many countries around the world, according to the work of the Intergovernmental Panel on Climate Change [39]. The increase in temperatures observed by a large majority of stations worldwide is an undeniable fact and thus confirms the reality of global warming [17].

Sub-Saharan Africa, like other regions of the world, faces extreme weather events such as rising temperatures and drought, which have impacted wheat cultivation. Given the importance of agriculture to the region's economy and rural livelihoods, climate change adaptation approaches appear essential.

Wheat production is of paramount importance to the economies of sub-Saharan Africa, but faces the challenges of global warming. This study aims to assess the dynamic effects of climate change (temperature variations) on wheat production in sub-Saharan Africa. To this end, the study used temperature difference as an indicator of climate change and control variables consisting of fertilizer consumption, agricultural land, rural population, commodity trade, and inflation. The panel ARDL model estimation method using the Mandala and Wu (1999) test is used to assess the short- and long-term effects of temperature variations on wheat production. The long-term results show that a 1 °C increase in temperature will lead to a decrease in wheat production in sub-Saharan Africa.

In the short term, the coefficient of variation in wheat production ( $L\_PBLELOG$ ) is positive and statistically significant at the 1% level. This indicates that producers respond to supply-side changes in wheat prices, but only in the short term. In the long run, the associated coefficient of the wheat production variable ( $lr\_PBLELOG$ ) is negative and statistically insignificant. This suggests that farmers in the sub-Saharan African region do not respond favorably to wheat prices in the short term. In both the short and long term, the coefficients of the temperature variation variable are negative. This suggests that climate change, in terms of rising temperatures, has a negative effect on wheat production in sub-Saharan Africa. Low temperatures would explain a large part of the low yields in the cereal sector, particularly wheat.

Finally, we can say that temperature variations negatively affect wheat production in both the short and long term over the period 1980 to 2022. This suggests that sub-Saharan Africa is vulnerable to climate change in terms of wheat production.

## Abbreviations

|                 |                                                       |
|-----------------|-------------------------------------------------------|
| ARDL            | Autoregressive Distributed Lag                        |
| ARSL            | Autoscaled Lag Regression                             |
| CO <sub>2</sub> | Carbon Dioxide                                        |
| FAO             | Fond and Agriculture Organization                     |
| IPCC            | Intergovernmental Panel on Climate Change             |
| OECD            | Organization for Economic Cooperation and Development |
| UECM            | Unrestricted Error Correction Model                   |

## Conflicts of Interest

The author declares no conflicts of interest.

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