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Economic Impact of Climate Change on Agricultural Production in Sub-Saharan Africa

Batru Wolde Muleta[1, 2, *], Aregawi Gebremedhin Gebremariam[1]

[1]School of Commerce, Addis Ababa University, Addis Ababa, Ethiopia

[2]Resource Management Office, Ethiopian Insurance Corporation, Addis Ababa, Ethiopia

Email address:
bawamu@gmail.com (Batru Wolde Muleta)

[*]Corresponding author

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Abstract: Agriculture is the main livelihood in Sub-Saharan Africa, but land degradation due to improper agricultural practices and climate change seriously causes a decline in yields. Climate change impacts agricultural production directly through temperature levels and water availability, and indirectly through its impact on disease vectors and pests. This paper investigates the economic impact of climate change on agricultural production in sub-Saharan Africa. Country-level panel data of sub-Saharan African countries are used to analyze the impact of temperature and precipitation on agricultural production. Deviations in temperature and precipitation from their long-term average are used in agricultural production models. The results indicate that a slight deviation in temperature from its long-term average impacts agricultural production positively and significantly, while its larger deviations affect production negatively. Both the slight and large deviation in precipitation impact agricultural production negatively and significantly. All agricultural production input variables have significant effects on agricultural production in the region. The study concludes by forwarding useful recommendations that base appropriate ecosystem management and production systems. The findings imply that the impact of climate change on agriculture is detrimental. To overcome the impact of climate change, the study suggests appropriate land use policy formulation, natural resource conservation, implementing best agronomic practices, and maintaining the population at an optimum level in the region.

Keywords: Sub-Saharan Africa, Climate Change, Agriculture, Panel Data

1. Introduction

Sub-Saharan Africa is home to more than 950 million people [26] and is known for its fast population growth, which is 2.5% per annum, compared to the 2017-2019 base period [27]. Agriculture is the main livelihood and absorbs more than 53% of total employment in the region [17]. On average, the sector accounts for 16% of the total Gross Domestic Product (GDP) of the region, though the contribution reaches more than 50% in countries like Chad [27]. However, more than half of the available land for agriculture is affected by land degradation, seriously causing a decline in yields in the region [16]. Improper agricultural practice and climate change have jointly accelerated both arable and pasture land degradation in the region [34].

Climate change worsens land degradation by increasing drought frequency and severity, dry spells, heat stress, rainfall intensity, flooding, sea-level rise, wind, and wave action adapted by land management. Its occurrences impact crop yield, animal growth rates, and productivity, as well as infestations by agricultural pests and diseases [20]. It impacts agricultural production directly through temperature level and water availability and indirectly through changes in other species such as pollinators, disease vectors, pests, and invasive species [12]. Climate change and its variability as well as extremes have been affecting agricultural productivity and natural resources that force food security, nutrition, and health challenges [13].

Climate change highly affects fruits and vegetables due to its potential cause of disease and pest infestations [36] and its impact on pollinators, which contribute up to 35% of worldwide crop production [18]. It also impacts livestock production systems, especially pastoralists, by decreasing animal feeds, productivity, poor animal health, and access to water [10].

Sub-Saharan Africa's population, which was 950 million in 2016, is projected to reach 2.1 billion by 2050 [26]. An increase in population imposes a burden on the increasing rate of urbanization, which lead to a decline in agricultural land as well as an increase in food demand [28]. Agriculture depends on natural resources like water, soil, and biodiversity, but agricultural policies mostly fail to include considerations of climate change impact [11] that results in loss due to natural disasters that arise from failure to integrate agriculture and environmental management policies [37].

This paper contributes to the literature by filling the knowledge gaps that are not addressed yet, through empirical evidence and in forwarding recommendations including policy issues. These also help to give a clear insight into how to adapt and mitigate climate change as well as coordinate resources to tackle the problem based on the link between climate change and agriculture. It mainly seeks to investigate the impact of climate change on agricultural production. Specifically, it aims to determine the impact of temperature and precipitation on agricultural production as well as to determine the vulnerability level of agricultural production to temperature and precipitation in SSA.

The remaining sections of this paper are organized as follows: The next section covers reviews of relevant literature. The third section covers the methodology, a part that includes research design, data source, data nature, method of data analysis, and model specification. The fourth section covers the discussion and presentation of both descriptive and empirical results. The final section concludes the paper and forwards possible policy options.

2. Literature Review

Climate change is a complex and uncertain problem that involves natural resources, the environment, and people's interactions which are likely to change the environment and influence agricultural production [8]. Changes in climate elements such as precipitation, temperature, and humidity, are likely to affect crop plants and livestock production, hydrologic balances, input supplies, and many parts of agricultural systems [9].

Agriculture is one of the most climate-sensitive sectors of an economy that is impacted positively or negatively by climate changes, as a result, of natural causes or human activities [38]. Crops need an optimal amount of heat, water, and nutrients, which are climatic in nature for the photosynthesis process [24], and necessary for crop survival and increased productivity [22]. However, extreme natural events such as drought, floods, windstorms, frost, heat spells, and erratic rainfall threaten agricultural productivity and production [19].

Climate change seriously affects both annual and perennial crop production. An increase in temperature, affects the length of the growing season, flowering, sterility, and protein content of the crop. The amount and distribution of precipitation increase erosion, flooding, storm damage, water lodging, and pest infestation rates. Under the successive influence of climate change on water availability, the spread of diseases and pests, and drought conditions; crops either have reduced yields or do not grow at all [8]. As with crops, the influence of climate change on forage yields, feed quality, water availability, heat stress, and the spread of pests and diseases has a substantial impact on livestock production, productivity, and the resilience of livestock production systems [31, 35]. It endangers fisheries and aquaculture along with water management practices because of rising water temperatures, a changing climate, a drop in pH, a decrease in oxygen levels, and changes in productivity patterns [14, 29].

Performance in the agricultural sector in SSA is limited by naturally low soil fertility, issues with governance, inadequate transport, and storage, poor access to inputs, and lack of infrastructure for the output market [2]. Among other developing regions, SSA faces the worst problem due to high temperatures and the reliance of inhabitants' livelihoods on rain-fed agriculture [6]. Only 4 percent of cultivated land is irrigated to prevent yield loss due to rising temperatures and a decline in precipitation [6, 15].

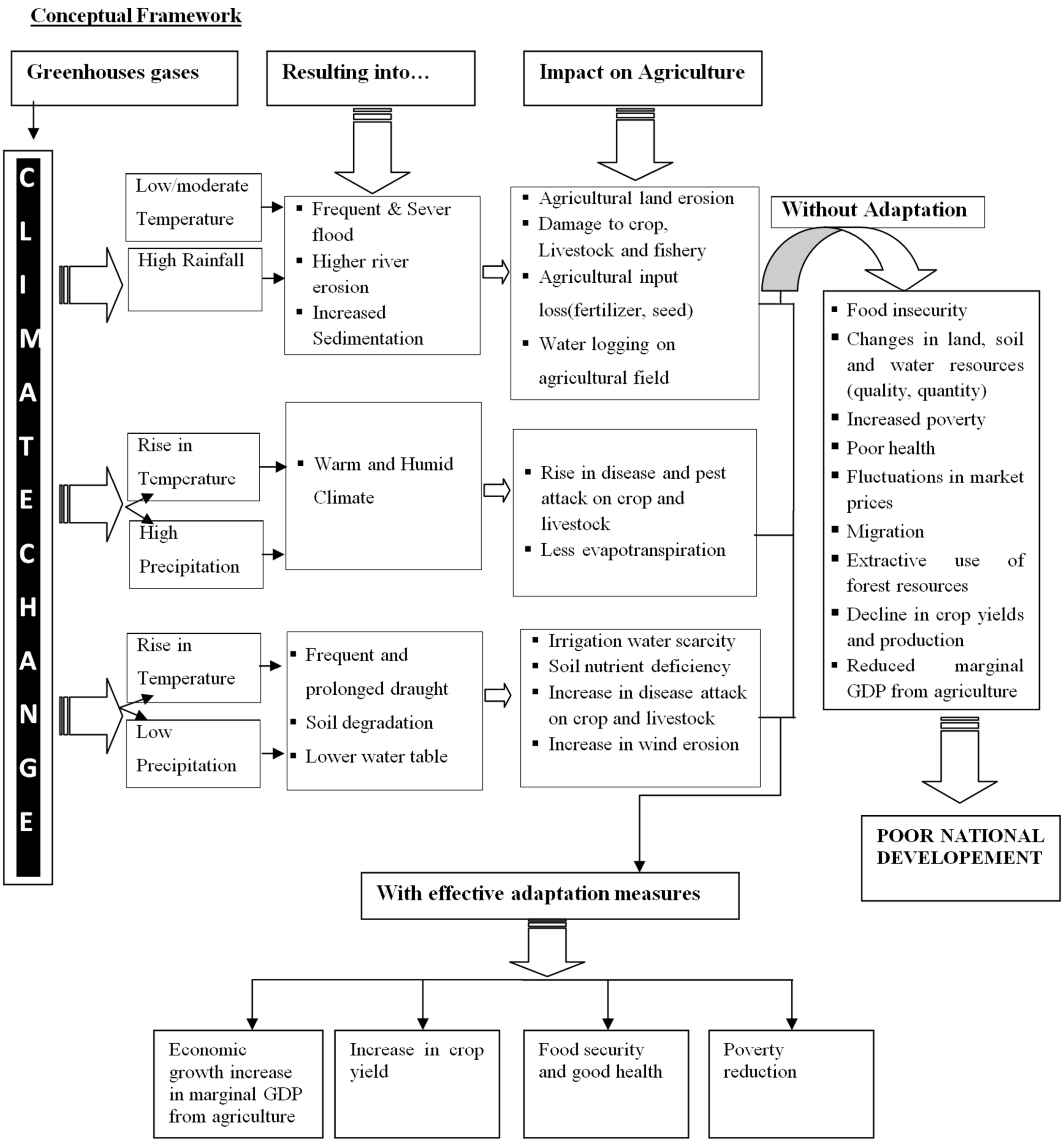
In SSA, about 80% of all the farms are smallholders that cultivate degraded small plots of land and lack reliable irrigation. They are classified as resource-poor farmers who practice rain-fed low-yield subsistence agriculture with yields that are below the global average because they lack input and financial credits. In 34 SSA countries, the average value added per worker is US$ 318, which is far less compared to the world average of US$ 1,000. Income is also less than US$1.00 per day, which is due to the low productivity of agriculture and people spend about 60% of their income on food [2, 6, 32].

Over 363 million people in the sub-Saharan Africa region experienced drought between 1980 and 2014; of them, 203 million lived in eastern Africa, 86 million in southern Africa, 74 million in western Africa, and less than 1 million in central Africa [3]. The prediction shows that future climate change's impact on developing countries is highly detrimental because of the widespread poverty level, high vulnerability levels, and low adaptation capacities of the region [30]. It is projected that by 2100, a decrease in crop yield ranges between 5 and 50% for wheat, between 20 and 45% for maize, between 30 and 60% for soybeans, and between 20 and 30% for rice respectively compared to a world without climate change and with the absence of mitigation mechanisms [33, 12]. Lobell, D. B., Bänziger, M., Magorokosho, C. and Vivek, B revealed that for each degree a crop spent above 30°C depresses yield by 1% if the plant gets sufficient amounts of water and the yield decreases by 1.7% for each day spent over 30°C under drought conditions in Africa [23]. In addition, an increase in temperature causes agricultural pest infestation and a damage rate, which causes yield reduction [5].

Kabubo-Mariara, J. and Karanja, F. K emphasize that, due to climate change, Kenya will experience an increase in average temperature between 3.5℃ to 4℃ and a 20% decrease in rainfall by 2030. According to forecasts, a change in temperature would result in a 1% (US$3.54 per hectare) gain in high potential zones but a 21.5% (US$54 per hectare) loss in medium and low potential zones. The results further suggest that losses of up to US$178 per hectare in the country by the year 2030 [21]. The prediction shows that, due to climate change, temperature increases of 2.5°C and 5°C cause $0.65 billion and $1.8 billion respectively in Cameron. In the same manner, an increase in precipitation causes a yield loss of 6.5% per hectare, and a further decrease in precipitation by 14% is predicted to cause a loss of $4.56 billion in Cameron [25].

Dell, M., Jones, B. F. and Olken, B. A. pointed out that high temperature reduces economic growth rates in poor countries by reducing agricultural output, industrial production, and political stability. According to their research findings in 136 countries, an increase in temperature by 1°C reduces economic growth by 1.3 percent on average [7]. Abidoye, B. O. and Odusola, A. F. revealed that many African countries experience a temperature increase of 10 to over 30 degrees Celsius due to climate change. This increase in temperature by 10 degrees Celsius leads to a decrease in GDP of 0.27% to 0.35%. An increase in temperature of 1.5℃ and 3.6℃ is estimated to reduce net revenue to $1,453.41 and 3,488.18 per hectare respectively; if adaptation is not incorporated [1]. However, reductions in net revenue are minimized to $116.67 and $280.01 per hectare for 1.5℃ and 3.6℃ increases in temperature respectively if farm machinery is used as an adaptation mechanism. Irrigation use could also increase farm net revenues by $39.26 and $94.21 per hectare for the same level of temperature increases [15].

Figure 1 Shows climate change's impact on agriculture and the effect of adaptation measures.



Source: Adapted from [4] with the amendment.

Figure 1. *Climate change impacts the agriculture sector and adaptation measures.*

3. Research Methodology

3.1. Research Design

To analyze the impact of climate change on agriculture, production approaches were used in the study. The study relied on panel data research design and fully depends on secondary data from all Sub-Saharan African countries. The secondary data used include the climate and economic variables data for a period of 30 years from 1989 to 2018.

3.1.1. Data Sources and Nature

For the statistical data analysis, unbalanced panel data was used in the paper. The empirical analysis is based on the panel data of SSA countries. Regarding data sources, temperature and precipitation data were collected from the World Bank climate change Portal website. The two years moving average is used from 2017 and 2018 years using stata for climate variables due to the unavailability of the data for the two years.

Economic variables such as the agricultural production index, the livestock production index, the total number of employees in the agricultural sector, agricultural land, fertilizers consumption, and pesticides used in agriculture were collected from the Food and Agriculture Organization of United Nations Statistics Division (FAOSTAT), World Development Indicator of the World Bank and Our World in data database.

3.1.2. Data Analysis and Presentation

Descriptive data analysis mean and standard deviations were used to compare the effect of variables. In addition, regression analyses were used to evaluate the relationships between dependent and independent variables. The outputs were presented by using text, tables, and graphs. Regarding software packages, Stata and eviews were used to analyze quantitative data. To identify the effect of climate change, the analysis controls agricultural inputs such as agricultural land, livestock, labor, irrigated land, the pesticide used, and fertilizers.

3.2. Model Specification

To investigate the effects of climate change on agricultural production, the study used a panel data production function approach (advanced Ricardian model). In order to explore climatic change's impact on agricultural production in SSA countries, the production function was specified in the study. This is where the agricultural production index is a function of a number of economic inputs and climate factors: Y=f (V, A, L, M, F, I, Pe, P, T). Where; V, A, L, M, F, I, Pe, P, and T represent the agricultural production index, the livestock production index, agricultural land (in hectares), labor, fertilizers, irrigated land, pesticide, precipitation deviation (mm), and temperature deviation (°C) respectively. Therefore, the panel data model (a two-way fixed-effects model) was used in this research analysis. In this analysis, the agricultural production model has the following specification form:

$$Y_{it}=\beta_o * V_{it}^{\beta 1} * A_{it}^{\beta 2} * L_{it}^{\beta 3} * F_{it}^{\beta 4} * I_{it}^{\beta 5} * Pc_{it}^{\beta 6} * e^{\beta_7 P_{it}+\beta_8 P^2 it+\beta_9 T_{it}+\beta_{10} T^2 it} * e^{\varepsilon_{it}} \quad (1)$$

Where; Y represents net agricultural production. According to the FAO, for every commodity, production quantities are weighted by 2014-2016 average international commodity prices and added for each year. Instead of using production quantities or local currency, "international dollars" was used as a unit of production. FAO explains that; to avoid exchange rate problems, obtain continental and world aggregates as well as simplify the international comparative analysis of productivity, international commodity prices are preferred use.

V stands for the livestock production index (2014-2016 = 100). A is agricultural land (in hectares) that refers to the part of the land that is arable, covered with permanent crops, and used as permanent grassland or grazing land. L represents the total number of employees in the agriculture sector as their livelihood. F represents the total NPK fertilizers used in agricultural production in Kilograms per hectare of agricultural land. I represent the area of land equipped for irrigation and Pe represents pesticide used in production in metric tons. Climate variables are precipitation and temperature. P represents precipitation deviation (mm), and T represents temperature deviation (°C) from their long-term mean.

3.3. Econometric Model

In many kinds of literature, the cross-section model, the experimental model, and the simulation model are the three most commonly used methods for studying climate impact. However, due to the characteristics of country-level panel analysis, which consider different countries over many years, temporal and regional scale variations are considered in the analysis. The panel data model given by equation (2) below is obtained after taking logs on both sides of the model specified above by equation (1) for any country "i" at a time "t".

$$\ln Y_{it}=\beta_o+\beta_1 \ln V_{it}+\beta_2 A_{it}+\beta_3 L_{it}+\beta_4 \ln F_{it}+\beta_5 \ln I_{it}+\beta_6 \ln Pe_{it}+\beta_7 P_{it}+\beta_8 P_{it}^2+\beta_9 T_{it}+\beta_{10} T_{it}^2+\mu_t+\alpha_i+\varepsilon_{it} \quad (2)$$

Where; lnY, lnV, lnA, lnL, lnF, lnI, and lnPe represent the logarithms of agricultural production index, livestock production index, agricultural land, labor, fertilizer consumption, area of irrigated land and pesticides used in agriculture respectively. P and T represent climate variables; precipitation and temperature, respectively. For climate variables, both the linear and square deviations were estimated in the model. The square deviations are included in order to give a larger weight for larger deviations.

Fixed effects were included in the model to capture time-invariant and unobserved country-specific effects, α, that may be correlated with the other regressors as well as to control for time differences in the dependent variable. Additionally, the time-varying effects μ, which are common to all countries, are proxies by a set of time dummies that are anticipated to capture factors like technological advancement. Finally, the error term is given by ε_{it}. The βs, for s = 1, 2, …, 10, are the coefficients to be estimated. For input variables that are expressed in natural logarithms form, their coefficients are interpreted as the elasticity of agricultural output with respect to each input.

4. Results and Discussions

4.1. Descriptive Result

Table 1 represents a summary of descriptive statistics for the relevant variables used in agricultural production. For all variables included in the analysis; mean, standard deviation, maximum value, and minimum values are presented below.

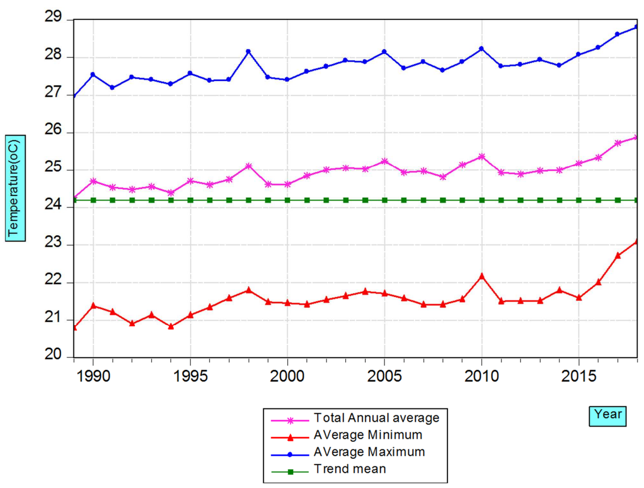
Table 1. *Summary of agricultural production inputs, economic and climate variables.*

Variable	Observation	Mean	Std. Dev	Min	Max
AGP (Y)	1,416	79.19104	24.70844	20.89	191.35
LIV	1,416	80.51907	26.09445	17	226.97
AGL	1,418	18900000	21200000	1500	98100000
EMP	1,392	3520165	5201443	11163.54	34300000
FERT	999	19.61572	49.15661	.01	398.93
IRGL_Ha	1,180	1168864	2909585	228	15100000
PESTC	1,007	1195.417	4127.772	1	26857
TEMP D	1,470	.7095551	.5633051	-.722140	2.855729
PREC D	1,470	-23.0275	182.8304	-1269.33	1230.357

Source: Own computation using stata software

4.2. Climate Change and Agricultural Production Trends in Sub-Saharan Africa

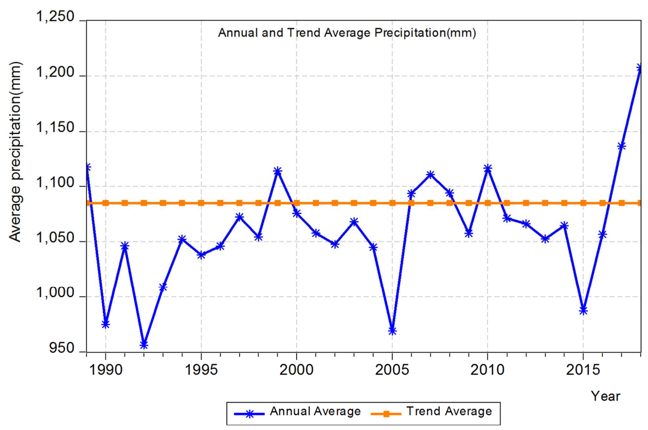
As shown in figure 2, during the study period from 1989 to 2018, the average annual temperature shows an increment. Both the annual average maximum and average minimum temperatures exhibit an increasing trend compared to the trend mean that was considered a value before the climate change era (1950).



Source: Author's Construction using Eviews software

Figure 2. *Maximum and minimum temperature deviation from long term mean in SSA.*

In Sub-Saharan Africa, the average precipitation trend reveals a decline in amount relative to the trend means with substantial variability during the study period. With the exception of six years (1998-1999, 2006-2008, and 2010-2011), the average annual rainfall over the study period was below the trend mean with high variability. However, starting from 2015-2018, the value increased sharply from 987mm to 1208 without a declining trend.



Source: Author's Construction using Eviews software

Figure 3. *Average Annual precipitation deviation from long term mean in SSA.*

4.3. Statistical Tests

Statistical tests were carried out to determine the model's robustness, the characteristics of error terms, and the long-run relationship between the variables, as well as to choose the best model for regression analysis. Since the results show the presence of autocorrelation, heteroskedasticity, and cross-sectional dependence, the Driscoll-Kraay estimator was employed in the regression to generate consistent standard errors. Regression analysis was performed using a fixed effect model based on the Hausman test result.

4.4. Econometric Result

Table 2 summarizes the fixed effect panel data analysis for the impact of climate change on agricultural production in SSA. The model analyzes data for 5 model versions given in equation (2) based on the regressors used. In models 1 and 2, the temperature results are not significant, but when the squared deviation is included, in models 3 and 4 it becomes statistically significant with a significance level of 5%. The temperature deviation has a positive effect on agricultural production, while the square deviation has a negative and statistically significant effect at a 5% level of significance. In model 4, an increase in temperature squared by 1°C results in a 3.6% decrease in agricultural production, while other factors remain constant. The result clarifies that the small temperature variation represented by the linear term favors agricultural production, but the squared deviation (larger deviation) impacts the production negatively in the region.

In all versions of the models, precipitation deviations and their square deviations negatively and significantly impact agricultural production. Keeping other factors constant, a 1mm increase in precipitation deviation from its long-term average, results in a 0.01% decrease in agricultural production. In all versions of the model, most agricultural production input variables show a significant and positive impact on agricultural production. Since all input variables are in logarithmic form, their interpretation is computed in elasticity form. The livestock production index has a positive relationship with agricultural production and is statistically significant at a 1% level of significance. This means an increase in the livestock production index by 1% results in an increase in agricultural production by about 0.5%, keeping other factors constant. The impact of agricultural land on agricultural production is positive and significant at a 1% level of significance. Keeping other variables constant a 1% increase in agricultural land results in an increase in agricultural production\n by about 1%. This shows agricultural production in the region is extensive farming that depends on natural resources.

Employment in agriculture impacts agricultural production positively as well as significantly. It is found to be significant at probability, which is less than 1%. The result obtained clarifies that agricultural production in the region is labor intensive employs a large number of labor forces, and is not mechanized. From the result, a 1% employment increase in the agriculture sector, results in an increase in agricultural production by 0.23%, keeping other factors constant.

Fertilizer is an important production input that has a positive impact on agricultural production and is statistically significant at a significance level of less than 1%. A 10% increase in fertilizer use results in a 0.27% increase in agricultural yield, holding other variables constant. Similarly, the use of pesticides as an adaptation mechanism to prevent yield losses due to pest and disease infestations has a positive effect on crop production with a level of significance below 5%. As seen in Model 5, holding other variables constant, a 10% increase in pesticide use on farms leads to a 0.14% increase in agricultural production. The impact of irrigation on agricultural production becomes significant when the pesticide is considered as an adaptation option.

Table 2. *Empirical results impact of climate change on agricultural production.*

Dependent Variable Agricultural production index (Apinx)					
Variables / Models	Model 1	Model 2	Model 3	Model 4	Model 5
Livestock pro. Index	0.573*** (0.0188)	0.571*** (0.0191)	0.562*** (0.0177)	0.561*** (0.0180)	0.510*** (0.0176)
Agri. Land	0.985*** (0.298)	0.991*** (0.30)	0.990*** (0.297)	0.994*** (0.300)	1.405*** (0.183)
Agri. Emp	0.229*** (0.0655)	0.233*** (0.0653)	0.235*** (0.0680)	0.238*** (0.0675)	0.221*** (0.0658)
Irrigated Land	0.112 (0.0174)	0.0103 (0.0175)	0.0137 (0.0190)	0.0128 (0.0191)	0.0376** (0.0173)
Fertilizer Used	0.0257*** (0.00644)	0.0268*** (0.00618)	0.0268*** (0.00615)	0.0273*** (0.00631)	0.0219*** (0.00641)
Pesticide used					0.0145** (0.00641)
Temperature Deviation	0.0222 (0.0209)	0.0206 (0.0213)	0.0810** (0.0304)	0.0774** (0.0305)	0.0859** (0.0401)
Temperature Sq. Deviation			-0.0381* (0.0214)	-0.0367* (0.0209)	-0.0400 (0.0240)
Precipitation Deviation	-0.000086** (0.000035)	-0.000104* * (0.0000377)	-0.000093** (0.0000364)	-0.000108** (0.0000396)	-0.000117** (0.0000512)
Precipitation Sq. Deviation		-0.000000158** (-0.000000074)		-0.00000013 (-0.00000008)	-0.00000016* (-0.00000008)
Constant	-17.73*** (3.963)	-17.87*** (4.006)	-17.93*** (3.935)	-18.04*** (3.982)	-24.70*** (2.370)
Observation	829	829	829	829	
Within R-Sq	.751	0.751	0.753	0.753	0.763
F-test	40.67***	38.19***	40.98***	38.09***	38.05***
Brausch Pagan LM test	1734.41***	1422.93***	1766.93***	1457.42***	921.74***
Ch2 of Hausman test	297.59***	302.70***	301.37***	303.37***	300.30***
Wooldridge test for Autocorrelation	32.514***	32.452***	33.440***	33.381***	26.954***
White's test for heteroskedasticity	213.93***	224.00***	218.12***	228.00***	244.05***

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

5. Conclusion

This paper analyzes the impact of climate change on agricultural production using panel data from SSA countries from 1989 to 2018. The study examines the impact of climate variables and agricultural input variables on agricultural production. The results show that a slight temperature deviation from its long-term average impacts agricultural production positively, while a larger deviation negatively and significantly affects production. However, when a pesticide is incorporated as a production input, the effect of square deviation on agricultural production no longer remains significant. This is due to the fact that pesticide helps as an adaptation mechanism to prevent yield losses from climate-related diseases and pest damage.

Based on the findings, the slight deviation in temperature favors the production in the region. This shows the average temperature in the region does not reach a damaging level for agricultural production. However, as the trend for average temperature shows an increasing trend, future damage is inevitable if the trend continues in a similar manner. For precipitation, both slight and larger deviations in precipitation from its long-term average have a negative and significant impact on agricultural production. This shows that agricultural production in the SSA region is sensitive to rainfall, showing that the production in the region is rain-fed agriculture. Likewise, agricultural production in the region is significantly and positively affected by livestock, labor, and land inputs, which confirms the dependence of regional agriculture on natural resources and labor-intensive that is not supported by technology or mechanized.

To minimize the damage the study recommends efficient use of irrigation and rainwater collection in areas where there is a severe rain shortage. In contrast, excess water has to be removed from water lodging agricultural fields using good drainage systems. The application of agronomic practices, such as planting multipurpose Agro-forest trees, adjusting the time of planting, and proper harvesting based on climate conditions to minimize yield loss at the field level due to climate factors should be practiced.

It is also important to invest in agricultural research to develop drought-tolerant, disease-resistant, high-yielding, and early-maturing varieties that require low water to reach maturity. Moreover, formulating and imposing viable policies with committed enforcement on Greenhouse gas emissions control, land use, and population growth to reduce ecosystem damage should be focused in the region.

Abbreviations

AGRA	Alliance for a Green Revolution in Africa
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agriculture Organization of United Nation Statistics Division
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IFAD	International Fund for Agricultural Development
IFPRI	The International Food Policy Research Institute
ILO	International Labor Office
IPBES	Intergovernmental Science-policy platform on Biodiversity and Ecosystem Service
IPCC	Intergovernmental Panel on Climate Change
ISS	Institute for Security Study
SSA	Sub-Saharan Africa

Authors' Contributions

The first author contributes to data collection, data summarization, data analysis and writing the manuscript, while the second author edits and structures the manuscript. Both the authors read and approve the final manuscript.

Availability of Data

Datasets generated during the current study are available in the Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT), World Development Indicator of the World Bank and our world in data database.

Competing of Interest

The authors declare no competing interest.

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