Research Journal of Agricultural Science, 58 (1), 2026; ISSN: 2668-926X;

http://doi.org/10.59463/RJAS.2026.1.05

CLIMATE CHANGE AND FOOD CROP PERFORMANCE IN TOGO: AN ECONOMETRIC ANALYSIS OF AGRICULTURAL YIELDS AND ADAPTATION STRATEGIES (1996–2025)

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Abstract. *This paper examines the effects of climate change and farmers' adaptation strategies on food crop yields in Togo over the period 1996–2025. Agriculture remains predominantly rain-fed and highly vulnerable to climate variability, making food production increasingly exposed to rising temperatures, irregular rainfall, and extreme weather events. While existing studies have mainly focused on temperature and precipitation, fewer have jointly considered broader climatic variables and farmers' endogenous adaptation responses at a disaggregated territorial level. Using a balanced panel dataset covering 33 prefectures and seven major food crops (corn, sorghum, rice, yam, cassava, beans, and peanuts), this study combines agricultural production statistics with meteorological data from national databases. The empirical analysis applies the Panel-Corrected Standard Errors (PCSE) method to address heteroskedasticity, autocorrelation, and cross-sectional dependence. Beyond temperature and precipitation, the model incorporates evapotranspiration, relative humidity, sunshine duration, and wind speed. Adaptation strategies are proxied by substitution and marginal agricultural lands to capture land reallocation decisions. The results reveal significant nonlinear relationships between climatic variables and crop yields. Extreme temperatures, excessive rainfall, and high evapotranspiration exert predominantly negative effects on productivity, although sorghum shows greater resilience to thermal stress. In contrast, corn, cassava, and beans are particularly vulnerable to heat and rainfall irregularities. Furthermore, land-based adaptation strategies do not improve productivity; marginal and substitution lands are associated with declining yields, suggesting that farmers expand cultivation onto less fertile lands as a coping mechanism rather than a productivity-enhancing strategy. The originality of this study lies in integrating extended climatic variables and endogenous land-use strategies into a prefectural panel framework. However, the analysis is limited by the lack of farm-level data and direct measures of technological adaptation. The findings support stronger policies promoting irrigation, climate-smart agriculture, improved seed varieties, and institutional support to enhance long-term food security.*

Keywords*: Climate change, Food crop yields, adaptation strategies, Togo*

INTRODUCTION

Agriculture is one of the economic sectors most exposed to the effects of climate change, particularly in developing countries where agricultural production remains highly dependent on natural conditions and rainfall (WHEELER and VON BRAUN, 2013; YUAN et al., 2024). In Sub-Saharan Africa, this vulnerability is particularly pronounced due to the predominance of rain-fed agriculture, low farm mechanization, and limited access to technological innovations (SULTAN et al., 2013; NSIAH and FAYISSA, 2019).

Climate change results in long-term modifications in climatic conditions, observable through changes in temperature, precipitation, relative humidity, evapotranspiration, solar radiation, and wind speed (ZHANG et al., 2017; LEGG, 2021; PROCTOR et al., 2025). These disturbances directly affect plant physiological processes, including photosynthesis, respiration, pollination, water absorption, soil fertility, as well as the proliferation of pests and diseases (ZHANG et al., 2017; ZHAO et al., 2017). As a result, agricultural yields exhibit strongly nonlinear responses to climatic variations, with particularly severe effects when biological thresholds are exceeded. For example, temperature increases beyond certain critical thresholds significantly reduce the productivity of corn, rice, and wheat, especially in tropical and semi-arid regions (HU et al., 2024; PROCTOR et al., 2025; REZAEI et al., 2023).

However, the effects of climate change on agricultural yields remain heterogeneous depending on crops, agroecological zones, and local adaptation capacities (ALI et al., 2017; AWOYE et al., 2017; ROPO and IBRAHEEM, 2017; HU et al., 2024). Cereal crops such as corn and rice often appear more sensitive to extreme temperatures than sorghum, which demonstrates greater thermal resilience (SULTAN et al., 2013; HOUNNOU et al., 2019). Nevertheless, the dominant literature concludes that negative effects generally outweigh positive ones, particularly in countries with weak institutional adaptation capacity (REZAEI et al., 2023). This differentiation implies that farmers develop various adaptation strategies to reduce yield losses induced by climate variability.

Faced with increasing climatic disturbances, farmers implement several adaptation strategies aimed at reducing yield losses. These mechanisms include crop diversification, adjustments in planting calendars, adoption of improved drought- or heat-tolerant varieties, supplementary irrigation, soil conservation practices, and the reallocation of agricultural land among different crops (CHEN et al., 2016; ZHENG et al., 2024). These strategies constitute rational responses to climatic shocks, but their effectiveness remains highly dependent on available resources, land quality, and the institutional environment.

Thus, climate change does not affect yields only directly; it also induces behavioral adjustments by producers. These adaptation strategies may themselves positively or negatively influence productivity depending on land quality and available resources. In several African contexts, land reallocation strategies often constitute more of a survival mechanism than a genuine lever for productive intensification (GRIGORIEVA et al., 2023).

In Togo, this issue is particularly important because agriculture remains largely rain-fed and plays a central economic and social role. BALAKA et al. (2021) highlight an upward trend in temperature, precipitation, and evapotranspiration, alongside declining relative humidity and solar radiation. These climatic disturbances directly affect major food crops such as corn, sorghum, rice, yam, cassava, beans, and peanuts, which are essential for household food security.

Beyond their direct effects on yields, these changes also influence farmers' production choices and adaptation strategies, which may either improve or reduce productivity. However, this dual relationship remains insufficiently explored in Togo, where most studies focus mainly on temperature and rainfall while neglecting other meteorological variables and land adaptation mechanisms. This article therefore examines the effects of climate change on food crop yields by explicitly integrating farmers' adaptation strategies through marginal and substitution land areas.

This study differs from previous works in two main respects. First, it broadens the analysis by incorporating a more comprehensive set of meteorological variables (relative humidity, evapotranspiration, sunshine duration, and wind speed) in addition to the traditionally used variables, namely temperature and precipitation. This approach makes it possible to better capture the complex and interdependent effects of climate change on agricultural production (REZAEI et al., 2023; ZHANG et al., 2017). Second, it introduces marginal and substitution land areas as control variables in order to assess the impact of land-based adaptation strategies on agricultural yields.

Using a prefectural panel dataset covering the period 1996–2025 and applying the Panel-Corrected Standard Errors (PCSE) method, the study highlights nonlinear relationships between climatic variables and agricultural yields, as well as the limited effectiveness of land reallocation adaptation strategies. These findings make an important contribution to the literature on the agricultural economics of climate change and provide useful guidance for public policies aimed at strengthening agricultural resilience, food security, and sustainable rural development in Togo.

MATERIAL AND METHODS

The literature on the effects of climate change on agricultural production mainly relies on three methodological approaches: manipulated experiments, process-based crop models, and empirical statistical models (FENG ET AL., 2023). Manipulated experiments provide strong control of environmental variables and reliable results, but they remain less suitable for macroeconomic analyses of agricultural yields. Process-based crop models capture biological growth mechanisms and allow long-term simulations over large areas, although they insufficiently account for extreme climatic events and farmers' endogenous adaptation strategies (WANG et al., 2022; FENG et al., 2023).

Empirical statistical models establish relationships between observed climatic variables and historical crop yields using regression techniques, panel models, and more recently machine learning methods. They are easier to implement, rely on widely available data, and are highly relevant for regional and historical analyses. However, they often face collinearity issues and limitations in capturing complex nonlinear effects (FENG et al., 2023).

For this study, the empirical statistical approach is the most appropriate due to the availability of climatic and yield data, its relevance for rain-fed agricultural systems, and its ability to capture farmers' behavioral adjustments. In addition, recent panel techniques improve the analysis of nonlinearities and spatial heterogeneity of climatic effects.

Theoretical Approach of the Analytical Model

The production function approach, particularly panel data analysis, is adopted. Taking yields into account makes it possible to integrate the different forms of farmers' adaptation to changing climate conditions into the analysis.

Following CHEN et al. (2016), the yield of crop j can be formalized as follows (Eq1):

$$\mathrm{Y_j = f(I_{i,j}, Q_j, Z, t)}$$

where t represents technological progress.

Model specification

The specification of the empirical model in this article assumes, following CHEN et al. (2016) and ZHANG et al. (2017), that the effects of meteorological variables on yields are cumulative and substitutable during the growing period. Thus, the agricultural response function to meteorological disturbances is specified as follows (ZHANG et al. (2017) (Eq2):

$$\begin{aligned} ln y_{ipt} = \int_{\underline{h}}^{\overline{h}} \mathrm{g}(h) \emptyset_{ipt}(h) dh + \partial h^2 + \gamma_1' \mathrm{Prec}_{ipt} + \gamma_2' \mathrm{Prec}_{ipt}{}^2 + \delta_1' w_{ipt} + \delta_2' w_{ipt}{}^2 + \beta' SO_{pt} \\ + Z_{pt} + \alpha_p + \tau_t + \varepsilon_{pt} \end{aligned}$$

where y_{ipt}, is the yield of crop *i* in prefecture *p* in *t* (measured in kg/ha) defined as production divided by cultivated area of the crop concerned; g(*h*) is the yield growth function of crop *i* in prefecture *p* in year *t* which depends on temperature *h*; $\underline{h}$ and $\overline{h}$ are the lower and upper observed limits of h during the growing season, respectively; $\emptyset_{ipt}$ is the temporal distribution of temperature during the growing season of crop i in prefecture p in year t; h^2, Prec_{ipt}^2 and w_{ipt}^2 represent respectively the quadratic terms of temperature, precipitation, and other meteorological variables; SO_{t} represents socioeconomic variables (marginal and substitution land areas) ; Z_{pt} is a weighting matrix describing the spatial dependence of prefectures relative to their neighboring prefectures ; α_p represents prefecture fixed effects ; τ_t represents year fixed effects used to eliminate unobservable factors common to all prefectures such as time shocks ; and ε_{pt} is the error term. Following the literature, quadratic terms of meteorological variables are used to analyze their nonlinear effects (CHEN et al., 2016; ZHANG et al., 2017).

Estimation method

In this article, the natural logarithm of y_{pit} is considered, and g(h) is estimated using dummy variables for each 13°C temperature interval. These dummy variables represent monthly exposures between minimum and maximum temperatures and are then summed over the entire growing season of crops. This makes it possible to examine whether nonlinear relationships exist between temperature and crop yields. For each prefecture, meteorological variables from the nearest weather station are considered and refer to the rainy season of the region to which the prefecture belongs.

Historical cultivated areas of the main crops are used to calculate marginal and substitution land conversion. The substitution area for a crop is the reduction in the sum of land allocated to all other crops compared with the previous year. It therefore corresponds to the reduction in land allocated to other crops and reallocated to a given crop. If the total land allocated to all other crops increases compared with the previous year, the substitution area for that crop is equal to zero. If the increase in the crop area compared with the previous year is smaller than the reduction in the sum of land allocated to all other crops, the substitution area is equal to the increase in the crop area.

The marginal area of a crop is defined as the difference between the increase in crop area compared with the previous year and the substitution area of the crop. It corresponds to newly cultivated land that had not previously been exploited but is allocated to the crop. If the increase in crop area compared with the previous year is smaller than the substitution area, the marginal area is equal to zero.

In order to capture the effects of variations in crop and input prices on yields, price ratios (the ratio between crop prices and fertilizer prices) are included as explanatory variables in the empirical model. This makes it possible to capture the role of fertilizer subsidies aimed at boosting fertilizer use and reducing the effects of climate change. Crop prices from year n-1 are used as approximations of expected crop prices for year n (CHEN et al., 2016).

Equation (2) is estimated separately for seven food crops: corn, sorghum, rice, yam, cassava, beans and peanut using the Panel-Corrected Standard Errors (PCSEs) method. This is done to correct for spatial correlation, heteroskedasticity, serial autocorrelation, and cross-sectional dependence in the residuals. All regressions of Equation (2) are weighted according to the cultivated area specific to each crop in order to correct for heteroskedasticity associated with each prefecture (SOLON et al., 2013).

Study area and data collection

The prefectural subdivisions considered in this article are those in force from 1996–2016 and consistent with the administrative map of Togo based on Law No. 2009-027 of December 3, 2009. The country is also subdivided into four (04) agroecological zones: coastal zone, forest zone, humid savannas, and dry savannas.

Data on yields, cultivated areas, and prices of the main food crops, as well as fertilizer prices, come from agricultural statistics of the ministry in charge of agriculture. Data relating to meteorological variables come from the National Meteorological Agency of Togo (ANAMET).

Table 1

Definition of variables in the estimation model for Equation 2

Variables	**Definition**
15-28 °C	Number of months during the rainy season with temperatures between 15–28 °C
18-31 °C	Number of months during the rainy season with temperatures between 18–31 °C
21-34 °C	Number of months during the rainy season with temperatures between 21–34 °C
24-37 °C	Number of months during the rainy season with temperatures between 24–37 °C
Precipitation (mm)	Total precipitation during the rainy season and its quadratic term
Evapotranspiration (mm)	Average evapotranspiration during the rainy season and its quadratic term
Sunshine duration (h)	Average sunshine duration during the rainy season and its quadratic term
Relative humidity (%)	Average relative humidity during the rainy season and its quadratic term
Wind speed (m/s)	Average wind speed during the rainy season and its quadratic term
Substitute land area (ha)	Dummy variable: 1 if there is substitute land area and 0 otherwise
Marginal land (ha)	Dummy variable: 1 if marginal land is present and 0 otherwise
Price ratio	Ratio of the price of the food crop to the price of fertilizers
Agroecological zones	Coastal, Wet savannas, Forests, Dry savannas
Yields (kg/ha)	Yield of the food crop in question

Sources: Authors

RESULTS AND DISCUSSIONS

The assumptions underlying the validity of the PCSE estimation method were tested. Tests were conducted for the absence of spatial correlation (Pesaran test (Pr < 5%) and Friedman test (Pr < 5%)), first-order autocorrelation (Wooldridge test (Pr < 5%)), and heteroskedasticity (Modified Wald test (Pr < 5%)). The results provide strong evidence of the existence of spatial correlations, autocorrelation, and heteroskedasticity in the error terms for all the crops studied. The Panel-Corrected Standard Errors (PCSEs) method corrects these problems.

The regression results (Tables 2) specifically reveal that extreme temperatures ranging between 21-34°C and 24-37°C reduce corn yields. The general upward trend in temperature would therefore further affect corn productivity. Rainfall has a positive but negligible effect on corn yields. This may be explained by the uneven distribution of rainfall during the rainy seasons. These findings are consistent with those of HOUNNOU et al. (2019) in Benin, ROPO AND IBRAHEEM (2017) in Nigeria, ZHANG ET AL. (2017) in China, and HU et al. (2024). Regarding additional climatic variables, the nonlinear U-shaped relationships between evapotranspiration, relative humidity, and corn yields indicate that these meteorological variables reduce corn yields, but at decreasing rates. This result is similar to that of ALI et al. (2017) who showed that increased relative humidity reduces corn yields in Ethiopia.

Contrary to the results obtained for corn, temperatures ranging from 21-34°C and 24-37°C improve sorghum yields. AWOYE et al. (2017) also found positive effects of rising temperatures on sorghum yields in Benin. The nonlinear U-shaped relationships between rainfall, evapotranspiration, relative humidity, and sorghum yields reveal that these meteorological variables reduce sorghum yields, but at a decreasing rate. The results suggest that the decline in sorghum yields would intensify with the general upward trend in rainfall and evapotranspiration observed in Togo. SULTAN et al. (2013) also found that rising evapotranspiration in East Africa reduced sorghum yields.

Table 2

Results of the estimation of Equation 2, controlling for climatic and socioeconomic variables

VARIABLES	**Corn**	**Sorghum**	**Rice**	**Yam**	**Cassava**	**Bean**	**Peanut**
15-28 °C	0.077***	-0.097***	0.046**	-0.054***	-0.055***	0.068***	0.101***
	(0.0133)	(0.0147)	(0.0232)	(0.0179)	(0.0214)	(0.0190)	(0.0193)
18-31 °C	0.027**	0.161***	-0.167***	-0.043**	0.062***	-0.129***	0.070***
	(0.0108)	(0.0196)	(0.0220)	(0.0208)	(0.0200)	(0.0163)	(0.0219)
21-34 °C	-0.069***	0.049***	0.126***	0.166***	0.070***	0.039**	0.003
	(0.0119)	(0.0178)	(0.0291)	(0.0200)	(0.0186)	(0.0162)	(0.0238)
24-37 °C	-0.038***	0.052**	-0.037	-0.024	-0.040**	-0.069***	-0.009
	(0.0107)	(0.0244)	(0.0248)	(0.0191)	(0.0167)	(0.0166)	(0.0168)
Precipitation	0.000***	-0.001***	-0.001***	-0.000*	-0.000**	-0.001***	0.000
	(2.81e-05)	(0.000249)	(0.000264)	(4.30e-05)	(4.56e-05)	(0.000216)	(5.81e-05)
Precipitation^2	0,46e-05**	0.000***	0.000***	-0,000***	4,14e-05***	0.000***	-2,90e-05
	(1,13e-05)	(1.12e-07)	(1.02e-07)	(1,94e-05)	(1,50e-05)	(8.12e-08)	(2,62e-05)
Evapotranspiration	-0.042**	-0.212***	0.095**	-0.028	0.242***	-0.046	-0.097***
	(0.0171)	(0.0347)	(0.0440)	(0.0274)	(0.0341)	(0.0301)	(0.0323)
Evapotranspiration^2	0.000**	0.001***	-0.000**	0.000	-0.001***	0.000	0.000***
	(5.78e-05)	(0.000114)	(0.000146)	(9.20e-05)	(0.000119)	(0.000101)	(0.000107)
Sunshine	-0.260	1.213***	-2.181***	-1.523***	-1.511***	-1.141***	-0.866**
	(0.168)	(0.224)	(0.320)	(0.257)	(0.340)	(0.259)	(0.378)
Sunshine^2	0.018	-0.099***	0.153***	0.119***	0.126***	0.081***	0.066**
	(0.0134)	(0.0173)	(0.0253)	(0.0204)	(0.0282)	(0.0206)	(0.0298)
Relative humidity	-0.095***	-0.205***	-0.177***	-0.245***	-0.391***	-0.370***	-0.121*
	(0.0344)	(0.0441)	(0.0644)	(0.0928)	(0.0889)	(0.0657)	(0.0626)
Relative humidity^2	0.001***	0.001***	0.001***	0.002***	0.002***	0.003***	0.001*
	(0.000231)	(0.000304)	(0.000438)	(0.000614)	(0.000580)	(0.000441)	(0.000427)
Wind speed	-0.068	0.096***	-0.211	-0.143*	0.039	-0.472***	-0.141
	(0.0480)	(0.0183)	(0.130)	(0.0845)	(0.0768)	(0.0851)	(0.0988)
Wend speed^2	-0.005		0.064*	0.030	-0.019	0.108***	0.027
	(0.0113)		(0.0334)	(0.0207)	(0.0175)	(0.0214)	(0.0241)

VARIABLES	**Corn**	**Sorghum**	**Rice**	**Yam**	**Cassava**	**Bean**	**Peanut**
Substitution areas	-0.000***	-0.000***	-0.000	-0.000***	-0.000***	-0.000***	-0.000***
	(3.56e-06)	(4.26e-06)	(1.27e-05)	(1.88e-05)	(3.72e-06)	(5.25e-06)	(1.71e-05)
Marginal areas	-0.000***	-0.000***	0.000	-0.000***	-0.000***	-0.000***	0.000
	(6.98e-07)	(1.54e-06)	(7.52e-06)	(7.47e-06)	(1.51e-06)	(1.97e-06)	(9.99e-06)
Price ratio	-0.127***	0.133***	-0.0653	-0.171***	-0.0644	-0.053***	-0.137***
	(0.0370)	(0.0376)	(0.0493)	(0.0438)	(0.0804)	(0.0193)	(0.0273)
Agroecological zones (coastal))							
Humid savannas	0.469***	0.327***	-0.192**	0.225***	0.121**	0.102	0.102*
	(0.0347)	(0.0927)	(0.0756)	(0.0478)	(0.0482)	(0.108)	(0.0614)
Forests	0.473***	0.200*	-0.133*	0.259***	0.226***	0.209*	0.330***
	(0.0365)	(0.116)	(0.0776)	(0.0542)	(0.0533)	(0.107)	(0.0658)
Dry savannas	0.399***	0.389***	0.005	-0.011	-0.466***	-0.179*	0.547***
	(0.0378)	(0.0910)	(0.0728)	(0.0521)	(0.0640)	(0.102)	(0.0579)
Constant	14.64***	27.19***	16.30***	23.64***	8.906**	27.79***	21.04***
	(1.752)	(3.594)	(4.202)	(3.569)	(3.716)	(2.952)	(2.901)
R-squared	0.765	0.936	0.964	0.710	0.975	0.950	0.963
Nomber of prefectures	33	25	27	27	29	33	33

Notes: The regression models are weighted by cultivated area. * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.
Source: Autthors

The nonlinear inverted U-shaped relationship between sunshine duration and sorghum yields shows that sunshine increases sorghum yields, but at a decreasing rate.

Temperatures ranging from 21-34°C improve rice yields. The effect of rainfall exhibits a nonlinear U-shaped relationship with rice yields. Rainfall therefore reduces rice yields, but at a decreasing rate. This may be explained by the general upward trend in rainfall. These results corroborate those of ALI et al. (2017), HOUNNOU et al. (2019), and ZHANG et al. (2017). Regarding additional meteorological variables, the nonlinear U-shaped relationships between sunshine duration, relative humidity, and rice yields reveal that these variables also reduce rice yields, but at a decreasing rate. In contrast, the effect of evapotranspiration presents a nonlinear inverted U-shaped relationship with rice yields, suggesting that evapotranspiration increases rice yields, but at a decreasing rate.

Temperatures ranging from 21-34°C and is beneficial to yam production. This result is consistent with that of HOUNNOU et al. (2019). The effects of sunshine duration, relative humidity, and wind speed exhibit nonlinear U-shaped relationships with yam yields. The negative effects of these variables on yam yields therefore decrease at a diminishing rate.

Cassava, on the other hand, responds negatively to extreme temperatures ranging from 24-37°C and to heavy rainfall. The general upward trend in rainfall and temperature would therefore be unfavorable to cassava production. HOUNNOU et al. (2019) also found a negative response of cassava yields to increasing temperature and rainfall. Similarly, AWOYE et al. (2017) and ROPO and IBRAHEEM (2017) reveal a negative relationship between cassava yields and rising temperatures. The nonlinear U-shaped relationships between relative humidity, sunshine duration, and cassava yields suggest that these meteorological variables reduce cassava yields, but at decreasing rates.

Extreme temperatures ranging from 24-37°C and rainfall also have negative effects on bean production. Bean cultivation is therefore threatened by the upward trend in temperature and rainfall. These results corroborate those of HOUNNOU et al. (2019) in Benin. AWOYE et al. (2017) also found that rising temperature is the main cause of declining bean yields in Benin. The effects of additional meteorological variables (relative humidity, sunshine duration, and wind speed) exhibit nonlinear U-shaped relationships with bean yields, suggesting that the negative effects of these variables on bean yields decrease at a diminishing rate. Similarly, the negative effects of evapotranspiration and sunshine duration on peanut yields decrease progressively. The upward trend in evapotranspiration observed in Togo therefore constitutes a threat to peanut production.

One of the major findings of this study concerns the impact of land-based adaptation strategies on agricultural productivity. Substitution areas show mixed effects. When they reflect a reallocation toward crops better adapted to new climatic conditions (such as sorghum), they improve yields. However, this effect remains limited. Marginal areas (for corn, yam, cassava, beans, and peanuts), by contrast, show a predominantly negative effect on yields. The expansion of production into new lands, often less fertile and less well developed, appears more as a survival strategy than as a genuine lever for productive intensification.

This result confirms the analyses DITTMER et al. (2023), according to which extensive adaptation through land expansion tends to reduce average productivity when it is not accompanied by investments in fertilization, irrigation, and soil restoration. Thus, climate change indirectly affects yields by altering farmers' land reallocation choices, but these adaptations remain insufficiently effective to offset productivity losses.

Changes in fertilizer prices have generally encouraged fertilizer use, with positive effects on the yields of corn, yam, beans, and peanuts. This indicates that these changes have led to increased fertilizer use and have positively affected the yields of crops. Beans and peanuts benefit from the residual effects of fertilizers applied to corn, with which they are often intercropped. These results are expected since fertilizer subsidies increase fertilizer use. Moreover, given the low soil fertility, food crops have become highly fertilizer-intensive crops for their growth. By contrast, the results show a reduction in fertilizer use for sorghum, with negative effects on yields. Indeed, sorghum is most often cultivated without fertilizer application. It mainly benefits from the residual effects of fertilizers applied to other crops with which it is intercropped.

Furthermore, this study shows that the effects of climate change vary across agroecological zones. It is observed that, on average, the forest, humid savannah, and dry savannah agroecological zones have higher yields than the coastal zone.

CONCLUSIONS

This article analyzes the effect of a broader set of interdependent meteorological variables on the yields of the main food crops in Togo over the period 1996–2025. The results show that climatic effects are highly nonlinear and differentiated across crops. Corn, beans, and cassava appear particularly vulnerable to excessive increases in temperature, whereas sorghum shows greater thermal resilience. Rainfall irregularities are harmful for sorghum, rice, cassava, and beans. Evapotranspiration, and the downward trend of relative humidity and sunshine duration in Togo generally exert a negative effect on yields, reflecting the intensification of water stress, while wend speed show variable effects depending on the crop.

In light of these findings, there is an urgent need for policymakers and farmers to strengthen mitigation, adaptation, and resilience strategies in the agricultural sector. Priority actions should include expanding irrigated agriculture, promoting climate-resilient crop varieties, and improving farmers’ technical capacities to sustain optimal yields.

Although this study improves understanding of the effects of meteorological variables and land reallocation strategies on food crop yields, it does not account for daily climatic data or certain adaptation practices such as individual irrigation and agroecological methods. Future research should use farm-level microeconomic data, integrate spatial dynamic approaches, and examine the distributive effects of climate change on rural poverty and food security.

BIBLIOGRAPHY

ALI, S., LIU, Y., ISHAQ, M., SHAH, T., ILYAS, A., DIN, I. U., 2017 – Climate change and its impact on the yield of major food crops: Evidence from Pakistan. Foods, 6(6), 39.

AWOYE, O. H. R., POLLINGER, F., AGBOSSOU, E. K., PAETH, H., 2017 – Dynamical-statistical projections of the climate change impact on agricultural production in Benin by means of a cross-validated linear model combined with Bayesian statistics. Agricultural and Forest Meteorology, 234–235, 80-94. https://doi.org/10.1016/j.agrformet.2016.12.010

BALAKA, M. M., YOVO, K., EGBENDEWE, A., 2021 – Spatio-Temporal Dynamics of Climatic Parameters in Togo. *Journal of Agricultural Economics and Rural Development*, *7*(1), 978-996.

CHEN, S., CHEN, X., XU, J., 2016 – Impacts of climate change on agriculture: Evidence from China. Journal of Environmental Economics and Management, 76, 105-124.

DITTMER, K. M., ROSE, S., SNAPP, S. S., KEBEDE, Y., BRICKMAN, S., SHELTON, S., EGLER, C., STIER, M., FENG, X., TIAN, H., CONG, J., ZHAO, C., 2023 – A method review of the climate change impact on crop yield. Frontiers in Forests and Global Change, 6, 1198186.

GRIGORIEVA, E., LIVENETS, A., STELMAKH, E., 2023 – Adaptation of Agriculture to Climate Change: A Scoping Review. Climate, 11(10), 202. https://doi.org/10.3390/cli11100202

HOUNNOU, F. E., DEDEHOUANOU, H., ZANNOU, A., BAKARY, S., MAHOUSSI, E. F., 2019 – Influence of Climate Change on Food Crop Yield in Benin Republic. Journal of Agricultural Science, 11(5).

HU, T., ZHANG, X., KHANAL, S., WILSON, R., LENG, G., TOMAN, E. M., WANG, X., LI, Y., ZHAO, K., 2024 – Climate change impacts on crop yields: A review of empirical findings, statistical crop models, and machine learning methods. Environmental Modelling & Software, 179, 106119.

HUANG, C., DUIKER, S., DENG, L., FANG, C., ZENG, W., 2015 – Influence of Precipitation on Maize Yield in the Eastern United States. Sustainability, 7(5), 5996-6010. https://doi.org/10.3390/su7055996

LEGG, S., 2021 – IPCC, 2021: Climate change 2021-the physical science basis. Interaction, 49(4), 44-45.

NSIAH, C., FAYISSA, B., 2019 – Trends in agricultural production efficiency and their implications for food security in sub-Saharan African countries. African Development Review, 31(1), 28-42.

PROCTOR, J., ZEPPETELLO, L. V., CHAN, D., HUYBERS, P., 2025 – Climate change increases the interannual variance of summer crop yields globally through changes in temperature and water supply. Science Advances, 11(36), eady3575. https://doi.org/10.1126/sciadv.ady3575

REZAEI, E. E., WEBBER, H., ASSENG, S., BOOTE, K., DURAND, J. L., EWERT, F., MARTRE, P., MACCARTHY, D. S., 2023 – Climate change impacts on crop yields. Nature reviews earth & environment, 4(12), 831-846.

ROPO, O. I., IBRAHEEM, A. A., 2017 – Response of cassava and maize yield to varying spatial scales of rainfall and temperature scenarios in Port Harcourt. Res. J. Environ. Sci, 11, 137-142.

SOLON, G., HAIDER, S., HAIDER, S., WOOLDRIDGE, J. M., 2013 – *What are we weighting for? Working paper/National Bureau of Economic Research, Inc.*

SULTAN, B., ROUDIER, P., QUIRION, P., ALHASSANE, A., MULLER, B., DINGKUHN, M., CIAIS, P., GUIMBERTEAU, M., TRAORE, S., BARON, C., 2013 – Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. Environmental Research Letters, 8(1), 014040.

WANG, E., HE, D., WANG, J., LILLEY, J. M., CHRISTY, B., HOFFMANN, M. P., O'LEARY, G., HATFIELD, J. L., LEDDA, L., DELIGIOS, P. A., GRANT, B., JING, Q., NENDEL, C., KAGE, H., QIAN, B., EYSHI REZAEI, E., SMITH, W., WEYMANN, W., EWERT, F., 2022 – How reliable are current crop models for simulating growth and seed yield of canola across global sites and under future climate change? Climatic Change, 172(1-2), 20. https://doi.org/10.1007/s10584-022-03375-2

WHEELER, T., VON BRAUN, J., 2013 – Climate change impacts on global food security. Science, 341(6145), 508-513.

YUAN, X., LI, S., CHEN, J., YU, H., YANG, T., WANG, C., HUANG, S., CHEN, H., AO, X., 2024 – Impacts of global climate change on agricultural production: A comprehensive review. Agronomy, 14(7), 1360.

ZHANG, P., ZHANG, J., CHEN, M., 2017 – Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. Journal of Environmental Economics and Management, 83, 8-31.

ZHAO, C., LIU, B., PIAO, S., WANG, X., LOBELL, D. B., HUANG, Y., HUANG, M., YAO, Y., BASSU, S., CIAIS, P., 2017 – Temperature increase reduces global yields of major crops in four independent estimates. Proceedings of the National Academy of Sciences, 114(35), 9326-9331.

ZHENG, H., MA, W., HE, Q., 2024 – Climate-smart agricultural practices for enhanced farm productivity, income, resilience, and greenhouse gas mitigation: A comprehensive review. Mitigation and Adaptation Strategies for Global Change, 29(4), 28. https://doi.org/10.1007/s11027-024-10124-6