УДК 338
JEL Q54, O13, C5

КЛИМАТИЧЕСКИЕ ИЗМЕНЕНИЯ И ИХ ВЛИЯНИЕ НА ПРОИЗВОДСТВО ЗЕРНОВЫХ В КОТ-Д'ИВУАРЕ

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Аннотация: Целью нашей работы является оценка влияния изменения климата на производство зерновых культур в Кот-д'Ивуаре. Для достижения этой цели мы использовали вторичные данные за период с 2000 по 2023 год. Эти данные взяты из базы данных Всемирного банка, в частности, по показателям мирового развития, а также с сайта rp5.ru. Для оценки влияния изменения климата на производство зерновых культур мы использовали модель множественной линейной регрессии. Результаты расчетов показывают, что изменение климата негативно влияет на сельскохозяйственное производство в Кот-д'Ивуаре.

Ключевые слова: изменение климата, сельскохозяйственное производство, метод наименьших квадратов

THE CLIMATE CHANGE AND ITS EFFECTS ON CEREAL PRODUCTION: CASE OF CÔTE D'IVOIRE

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Abstract: The objective of our work is to assess the effects of climate change on cereal production in Côte d'Ivoire. To achieve this objective, we used secondary data for the period from 2000 to 2023. These data come from the World Bank database specifically on world development indicators and from the rp5.ru website. To assess the effects of climate change on cereal production, we used the multiple linear regression model. The results of the estimations show that climate change negatively influences agricultural production in Côte d'Ivoire.

Keywords: climate change, agricultural production, ordinary least squares.

Introduction. Climate change has become one of the major challenges of the 21st century, with significant impacts on various economic sectors, particularly agriculture. Côte d'Ivoire is a country located in West Africa, with an area of 322,462 km², bordered by the Atlantic Ocean to the south, and sharing borders with Liberia, Guinea, Mali, Burkina Faso and Ghana, agriculture plays a crucial role in the economy and food security. The country is characterized by climatic diversity, ranging from equatorial climate in the south to tropical climate in the center, to sub-Saharan climate in the north. This climatic diversity has a direct influence on agricultural systems, particularly cereal production, which is an essential component of the diet and income of rural populations.

However, the effects of climate fluctuations are increasingly being felt on production, with temperature variations, erratic rainfall and extreme weather events directly affecting crop productivity, threatening farmers' livelihoods and the country's food stability.

Although several studies have explored the impact of climate change on agriculture at the global level, few of them focus on the Ivorian context, a country marked by climatic plural diversity. The approach of this research is therefore to fill this gap by analyzing the effect of climatic factors on cereal production in Côte d'Ivoire.

The novelty of this study lies in the use of a multiple linear regression model that integrates both climatic variables and economic indicators. This model will allow us to better understand the complex relationships between climate and agricultural production, and to propose solutions adapted to the specific Ivorian context.

In view of this context, we can ask ourselves the following question: How does climate change influence cereal production in Côte d'Ivoire?

Thus, the general objective of this study is to analyze the effects of climate change on cereal production in Ivory Coast. This objective is subdivided into two specific objectives namely:

Specific objective 1: Evaluate the climatic determinants on cereal production

Specific objective 2: Analyze the State policy in improving cereal production

To achieve these specific objectives, we formulate the following hypotheses:

Hypothesis 1: The amount of rainfall positively affects cereal production

Hypothesis 2: The measures taken by the State improve the producers' cereal production.

At the methodological level, to answer the question of the problem and verify our hypotheses, our methodology consists of doing an econometric analysis, which will consist of establishing the multiple linear regression model, which will relate climate change and agricultural production. In addition, the data used are secondary data and come from the World Bank database on the World Development Indicator and the Raspisaniye pogodi Ltd database over a period of 24 years from 2000 to 2023. The software used to make the estimates are Excel 2021 and Eviews 12.

Literature review. To quantify the links between climate and agriculture, a prerequisite is to build a model that can translate climate information (e.g. temperatures and/or precipitation) into agronomic variables (agricultural yields, biomass). This type of model is particularly useful for synthesizing existing knowledge on climate/plant relationships, exploring hypotheses of climate change or agricultural practices, identifying key variables on which research should focus, and building scenarios for the future. Two distinct approaches are generally used: the first is based on statistical agronomic models and the second on mechanistic models, both seeking to estimate agricultural productivity in response to climate. Empirical agricultural models are based on a statistical relationship derived from observed data and linking agricultural yields, at a given location, to climatic variables. Although such a relationship is relatively easy to establish, calibrating and validating a robust statistical model requires long data series (climate and yields). This relationship, however, has a notable advantage, since it can be established directly at a large scale (e.g. national) using spatially aggregated climate data, in order to predict yields over large regions. This approach is notably used by Lobell et al. (2008) and Schlenker and Lobell (2010) who consider that it allows a simple assessment of future climate impacts at a scale relevant to inform decision-makers.

"Mechanistic" or "dynamic" modeling is based on equations representing the physiological processes of crop growth (assimilation of carbon and nutrients, transpiration, etc.) and their development in response to climate (e.g. appearance of successive organs, vegetative and reproductive phase, etc.). Given that this approach theoretically allows capturing the intra-seasonal and non-linear effects of climate on crops, most impact studies in agriculture use a mechanistic model (Roudier et al., 2011). However, not all models of this type have the same physiological approach and do not reach the same level of detail. In particular, the positive effect on photosynthesis of a high atmospheric concentration of CO2 (Tubiello et al., 2007) is not taken into account in all mechanistic models (e.g. Salack, 2006). Furthermore, these models require many parameters and are therefore used at the plot scale where these data are available and can be considered homogeneous: they do not directly provide information on climate impacts on a larger scale.

The Ricardian model (Mendelsohn et al., 1994) is also used to estimate the impact of climate change on agriculture in West Africa (e.g. Kurukulasuriya and Mendelsohn, 2008; Molua, 2009). This approach focuses on net farm income rather than crop yields and, unlike most impact studies, takes into account adaptation strategies. The Ricardian approach generally proceeds in several major steps:

1) collecting socio-economic information on farms;

2) calculating the net farm income using this information;

3) running a regression between the calculated net income and different variables such as climate, soil and a set of economic variables; and

4) using the established link between income and climate to project the impact of future climate. Note that unlike empirical approaches, the regressions carried out here are only for one year: this is therefore a study of spatial variability.

The assessment of the effect of climate change on agricultural production has been the subject of several studies. Among the works carried out in this regard, we mention that:

- (Reilly, 1995), concluded that considerable progress has been made in assessing the potential effects of climate change on global agriculture, but significant uncertainties remain. As existing data indicate that global effects are manageable, concern has shifted to regional effects.

- (Easterling, Crosson, Rosenberg, Mc Kenney, Katz, & Lemon, 1993), determined that the lack of technology improvement and CO2 enrichments, could generate a lowering of production and consequently a cause of economic weakening.

- (Rosenzweig & Parry, 1994), showed that assessment of the impact of climate change on global food supplies suggests that doubling the atmospheric concentration of carbon dioxide will lead to a decrease in global agricultural production.

- (Mendelsohn, 2008), concluded that global warming causes the greatest damage to agriculture in developing countries, mainly because many farms experience too hot climates. Moreover, the economic impact of climate change affects agriculture due to the size and sensitivity of the sector. (Zouabi, 2015), concluded that the water available in the governorate's water table can be an effective solution for the farmer who resides there provided that the means are implemented so that he can benefit from it. Also, the effect of temperature via the water resources of the governorate and neighboring governorates represent a negative spillover effect;

- (Woillez, 2019), concluded that Morocco is therefore at risk of experiencing an exacerbation of already difficult conditions and of facing more intense and/or more frequent periods of drought. This aridification, which will be all the more marked as the level of global warming is high, will have significant consequences on the country's water resources and therefore, among other things, on the agricultural sector.

Econometric analysis of the effects of climate change. To study the effect of climate change on cereal production in Côte d'Ivoire, we chose a multiple linear regression model. This choice is justified by the fact that this model has the capacity to analyze the simultaneous influence of several exogenous variables, such as precipitation, temperature, CO2 emissions and cultivated land, on the endogenous variable, which is cereal production.

The multiple linear regression model has the advantage of being able to quantify the individual impact of each climate factor, while controlling for the effects of other variables. This allows for a more precise and nuanced analysis of the combined effects of climate change. In addition, the data used cover a period of 24 years, i.e. (2000-2023), which provides an important database for assessing long-term trends.

The multiple linear regression model is a model composed of an equation in which an endogenous variable is explained by several variables. The parameters of this model are estimated by the ordinary least squares (OLS) method when certain random factors on these hypotheses are respected. The multiple linear regression model is written as:

$$Y = X\beta + \varepsilon \quad \text{with}$$

$$\underset{(N,1)}{Y = \begin{pmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_N \end{pmatrix}}, \underset{(N,K)}{x = \begin{pmatrix} 1 & x_{21} & \cdot & \cdot & x_{k1} \\ 1 & x_{22} & \cdot & \cdot & x_{k2} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ 1 & x_{2N} & \cdot & \cdot & x_{KN} \end{pmatrix}}, \underset{(K,1)}{\beta = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_k \end{pmatrix}}, \quad \underset{(N,1)}{\varepsilon = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_N \end{pmatrix}}$$

N indicates the number of observations contained in the model (*i = 1,…,N).* The number of parameters to be estimated is equal to *K* (k = 1,…, *K*).

$$y_i = \beta_1 + \beta_2 x_{2i} + \cdots + \beta_K x_{Ki} + \varepsilon_i \quad i = 1, \ldots, N$$

$$= [\beta_1 \quad \beta_2 \ldots \beta_k] \begin{bmatrix} 1 \\ x_{2i} \\ \vdots \\ x_{ki} \end{bmatrix} + \varepsilon_i = \beta' x_i + \varepsilon_i$$

$$= [1 \quad x_{2i} \ldots x_{ki}] \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_k \end{bmatrix} + \varepsilon_i = x'_i \beta + \varepsilon_i$$

Y: the vector of *N* observations y_i on the endogenous variable of the model or explained variable of the model

X: the matrix of exogenous variables of the model. Each column is an explanatory variable of the model. This is a model with constant because the vector composed only of the value 1 appears in the matrix.
β: the vector of parameters to be estimated. There are K parameters to be estimated since there are K explanatory variables. β' is the transpose of the vector β
ε: the vector of random variables. Random variables take into account the fact that the relationship between the endogenous variable and the different explanatory variables is not exact (Isabelle Cadoret, Applied Econometrics 2nd, 2009).

So, the model looks like this:
$GRAIN_i = \beta_0 + \beta_1 CO2_{1i} + \beta_2 DIS_{2i} + \beta_3 LAND_{3i} + \beta_4 PRECI_{4i} + \beta_5 TEMP_{5i} + \varepsilon_i$ .i = individual i

β_0 is the constant term; are the respective coefficients of the explanatory variables. is the error term;
i is the index relating to the country.β_0, $\beta_{1,}$ β_2 $\beta_{3,}$ $\beta_{4,}$ $\beta_{5,}$ ε_i

Data source. The data comes from highly reliable sources, including the World Bank website and RP5.ru, thus ensuring the rigor of the results. The software used, Excel and Eviews, allows for in-depth statistical analysis, ensuring the reliability of the conclusions.

Table 1: Variables and data source

Variables	Description of the variable	Data source
Grain	grain production (metric tons)	World Bank
CO2	Total greenhouse gas emissions (kt of CO2 equivalent	World Bank
DIS	Disbursement of official development assistance for the agriculture, forestry and fisheries sector in dollars	World Bank
LAND	Land cultivated with cereals (hectares)	World Bank
PRECI	Average precipitation height	RP5.RU
TEMP	air temperature at 2 m above ground surface	RP5.RU

Source: Authoring, from literature

Estimation procedure. The assumption of normality of the error term plays an essential role because it allows us to specify the statistical distribution of the estimators. The normality test on a variable is formulated as follows:

H_0 : X following a normal law N(m,δ)

H_1 : X does not follow a normal distribution N(m,δ)

-If Jarque-Berra > Khi-square at ddl or if P-value < 0.05; we reject the hypothesis of normality of X, that is to say that X does not follow a normal distribution *N(m,δ)*

-If Jarque-Berra < Chi-square at ddl or if P-value > 0.05; we accept the hypothesis of normality of X, that is to say that X follows a normal distribution *N(m,δ)*.

The overall significance test of the model is used to judge the quality of a model. This is a Fisher test that is based on the construction of the analysis of variance table

Table 2 - Analysis of variance

Source of variation	**Sum of squares**	**Degree of freedom**	**Medium square**
$x_{1t}, x_{2t}, \ldots, x_{kt}$	$SCE = \sum_{t=1}^{n} (\widehat{y_t} - \bar{y})^2$	*K*	*SCE/k*
Residue	$SCR - \sum_t e_t^2 - \sum_{t=1}^{n} (y_t - \hat{y}_t)^2$	*n – k -1*	SCR/(n – k – 1)
Total	$SCT = \sum_{t=1}^{n} (y_t - \bar{y})^2$	*n -1*	

Source: Régis Bourbonnqis 9th edition

The overall significance test of the model is a generalization of the Student test, which is why it is formulated as follows:

$H_0 : a_1 = a_2 = \ldots = a_k = 0$

H_1*: there exists at least one non-zero coefficient* a_i *(i=1…k)*

Under the hypothesis H_0, follows a Fisher distribution (ratio of two chi-square) thanks to the hypothesis of normality of errors. We therefore compare this calculation to the theoretical *F* at *k* and *(n - k - 1)* degrees of freedom for a given threshold of *α*. If $F_{cal} > F_{lu}$ or the p-value is less than 0.05 we reject the hypothesis H_0, the model is globally significant.

Presentation of the results of the econometric tests and interpretations. The coefficient of determination is 0.619, or 61.9%, which means that the regression equation explains 61.9% of the variations in the dependent variable. In other words, the variation in cereal production (dependent variable *GRAIN*) is explained by the independent variables of the model (*CO2, DIS, LAND, PRECI, TEMP*). The model explains quite well the relationship between climatic factors and cereal production in Côte d'Ivoire.

Table 3 - Linear Regression

Dependent Variable: GRAIN		
Method: Least Squares		
Included observations: 24		
Variable	Coefficient	Prob.
C	-11331591.82264944	0.2374503080417589
CO2	-85.46637236463878	0.08234295105596645
DIS	0.0052156960146130 7	0.0398231962505839
LAND	0.4946217161953608	0.02792533896059204
PRECI	189.6089361996691	0.02428870173551988
TEMP	540563.0142411644	0.1474172897272524
R-squared	0.6190201200470076	
F-statistic	5.84931790215323	
Prob(F-statistic)	0.002224090683214862	
NORMALITY OF ERRORS: JARQUE-BERA TEST (Probility)	0.71563	

Source: Authoring, based on data from the World Bank and RP5.RU

Regarding the Fisher, the probability associated with this statistic is 0.0022, which is less than 0.01. This means that the model is globally significant at the 1 % level. In other words, there is at least one of the explanatory variables (CO2, DIS, LAND, PRECI, TEMP) that significantly influences cereal production. The model is therefore appropriate to explain the impact of climatic factors on cereal production in Côte d'Ivoire.

The Jarque-Bera error normality test shows that the errors are normally distributed at the 5% threshold because the p-value associated with the statistic is greater than 0.05This also means that we cannot reject the null hypothesis of normality of the residuals (errors). Thus, the residuals follow a normal distribution, which is an important condition for validating the statistical tests used in regression analysis.

Interpretations of individual variables.

- **CO2** (probability = 0.0823 coefficient = -85.47) : the coefficient applied to the CO2 variable is -85.47, indicating that all things being equal, an increase of 1 unit of kiloton of CO2 emissions leads to a decrease of 85.47 tons in cereal production. Although the effect is negative, the probability associated with CO2 (p = 0.0823) is slightly higher than the 5% threshold, meaning that the effect is significant at a 10% confidence level. This shows that there is a trend towards a negative impact of CO2 emissions on cereal production. More explicitly, CO2 emissions show a negative effect, although slightly less significant. This suggests that greenhouse gas emissions deteriorate the climatic conditions necessary for optimal agricultural production, which highlights the real need to reduce these emissions to improve agricultural yields in the long term. Note that this relationship should be interpreted with caution.
- **DIS** (Probability = 0.0398, Coefficient = 0.0052) the probability applied to the variable disbursement of public aid is statistically significant at the 5% threshold because the P-value is less than 0.05. The coefficient applied to this variable is 0.0052. An increase of one unit in dollars of disbursement of public development aid would lead to an increase of 0.0052 tons of cereal production in Côte d'Ivoire. All other things being equal. The coefficient is small, but it still indicates a positive relationship between official development assistance and cereal production.
- **LAND** (Probability = 0.0279, coefficient =0.494) the coefficient applied to the variable LAND is 0.494. This means that an increase in cultivated land of 1 hectare would lead to an increase in cereal production of 0.494 tons. This coefficient is very insignificant, this may be due to the fact that farmers do not have enough means to buy phytosanitary products to maintain their orchards and also that the land is heavily exploited, which makes the land infertile. The probability applied to this variable is significant. The expansion of cultivated land has a direct and positive impact on cereal production.
- **PRECI** (coefficient: 189.608, probability: 0.0242) an increase of 1 millimeter of rainfall leads to an increase in cereal production of 189,608 tons, all other things being equal. The high coefficient indicates a positive and substantial impact of rainfall on cereal production. In other words, we say that the results of the econometric analysis reveal several key points about the effects of climate change on cereal production in Côte d'Ivoire. Precipitation appears to be a determining factor, with a positive and significant effect on cereal production. An increase in rainfall leads to a substantial increase in cereal production, thus confirming the importance of efficient water management in the country's agricultural practices.
- **TEMP** (probability = 0.1474coefficient = 540563.01**):** the coefficient applied to the temperature variable is540563.01. This indicates that an increase in temperature of

one degree would lead to an increase in cereal production of 540563.01 tons. But this effect is not statistically significant because the associated p-value is 0.1474. This effect can not be considered significant in our model.

Although increasing temperatures appear to have a positive effect on cereal production, this effect is not statistically significant, suggesting that other factors, not taken into account in this model, could influence the relationship between temperature and cereal production in Côte d'Ivoire.

These results confirm that climate change, by affecting key variables such as precipitation and CO2 emissions, plays a crucial role in the fluctuation of cereal production in Côte d'Ivoire. Proactive management of these elements is important to ensure the country's food security.

Perspective of the study. The results of this study show that climate change significantly impacts cereal production in Côte d'Ivoire, and this has enormous implications for the national economy. Agriculture represents a significant share of Côte d'Ivoire's gross domestic product and cereals are a staple food for a large part of the Ivorian population. Therefore, climatic variations that negatively affect cereal production risk destabilizing the agricultural economy and increasing food insecurity.

One of the main implications of the results is the need for the State of Côte d'Ivoire to strengthen its agricultural policies, particularly in terms of water resource management. The importance of rainfall in cereal production highlights the urgent need to invest in more efficient and resilient irrigation systems, capable of overcoming periods of drought.

In addition, reducing CO2 emissions must become a priority for the Ivorian agricultural sector. Sustainable agricultural practices, such as agroforestry or soil regeneration, could be implemented to limit the negative impact of greenhouse gases on agricultural production. The adoption of such practices could not only improve productivity, but also make Ivorian agriculture more resilient to climate change.

Strengthening public policies: The State must further intensify agricultural support policies by increasing funding and investing more in agricultural infrastructure, particularly in irrigation and fertilizers.

Reducing CO2 emissions: Measures that are more appropriate need to be taken to reduce greenhouse gas emissions, as they have a negative impact on agricultural production. This could include sustainable farming practices and greener technologies to limit the carbon footprint of the agriculture sector.

Improved agricultural land management: Agricultural land needs to be better managed to improve its fertility, including using agroecological techniques and soil regeneration. An expansion of cultivated land alone is not enough without appropriate and sustainable practices.

Encourage climate change adaptation measures: Farmers must be trained to adopt resilient agricultural practices, such as crop diversification and the introduction of new climate change adaptation techniques.

Conclusion. This study allowed us to show the impact of climate change on cereal production in Côte d'Ivoire. The results we obtained from the multiple linear regression model reveal that rainfall and the extension of cultivated land have a positive and significant effect on cereal production, while CO2 emissions negatively influence this production. Although an increase in temperature seems to have a positive effect, this effect is not statistically significant in this model. In addition, public aid for the development of agriculture also has a positive, although moderate, effect on cereal production. This shows the importance of public policies in improving agricultural productivity. However, to maintain and increase cereal production in the face of the challenges posed by climate change, additional efforts are needed in terms of sustainable land management, reduction of greenhouse gas emissions, and adaptation of agricultural practices to new climatic realities.

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Поступила в редакцию 15 ноября 2024 г.