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Measuring the impact of climate change on cereal production in Sub-Saharan Africa.

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Abstract

The aim of this study is to measure the impact of climate change on cereal production in Sub-Saharan Africa. It was based on average monthly rainfall and temperature over the crop period, and annual data for other variables over the period 1990 to 2022. Three estimation methods were used, including fixed-effects and random-effects models, and the Feasible generalized least squares (FGLS) model. The results of the FGLS model showed that rainfall has a negative effect on maize production. On the other hand, the results revealed an ambiguous effect of temperature on the production of different cereals (positive for millet and rice production and negative for maize production). In order to reduce the adverse effects of climate change on agriculture, this study justifies the need for Sub-Saharan African countries to increase investment in irrigation practices and to encourage investment in agricultural innovation projects.

Keywords: climate change, cereal production, irrigation, Sub-Saharan Africa, FGLS model

Introduction

Climate change and its consequences represent one of the most significant threats to biodiversity and ecosystem functions (Ding & Nunes, 2014; Omann et al., 2009). It is one of the major challenges of our time, with issues that are both highly complex and constantly evolving. The decline of forests as a result of fires, altered precipitation patterns and high levels of drought is seriously affecting their climate regulation role. Furthermore, warming and increased precipitation favor the spread of disease vectors such as mosquitoes, with drastic consequences for the health of millions of people worldwide (Warren et al., 2021).

Against this alarming backdrop, agriculture is one of the sectors most sensitive to climate change. Agricultural land is directly exposed to changing weather conditions (Ahmed et al., 2015; Blanc & Schlenker, 2017). In addition, climate fluctuations increase the number of insects, weeds and diseases, which has an indirect negative impact on crop yields, making crop management difficult and costly (Abdi et al., 2022). Changes in agricultural supply resulting from the combination of changes in yields and cultivated area result in increased food costs, and the ability to procure food will be directly affected (Adams et al., 1998; Ochou & Quirion, 2022).

More specifically, in sub-Saharan Africa, the characteristics of the geography and farming practices make its agricultural sector particularly sensitive to climate change (Barrios et al., 2008; Boubacar, 2010; Roudier et al., 2011). Moreover, Africans are disproportionately employed in climate-exposed sectors, with around 55% to 62% of the workforce in sub-Saharan Africa employed in agriculture IPCC (2022) and 95% of cultivated land is rainfed (Calzadilla et al., 2013; IPCC, 2022). In developing countries such as those in Sub-Saharan Africa, climate change is a direct catalyst for increasing food insecurity, especially among children, the elderly and in female-headed households, hampering efforts to achieve sustainable development goals and slowing economic growth (IPCC, 2022).

As a result, the estimated impact is particularly heavy for developing countries, where agriculture is directly responsible for the livelihoods of a large proportion of the population, and where adaptive capacity is limited (Nguyen & Scrimgeour, 2022). This is why the impacts of climate change on agriculture in sub-Saharan Africa, and the most effective investments to facilitate adaptation to these changes, are of great interest to researchers and decision-makers alike (Schlenker & Lobell, 2010). It seems important that African policy-makers take specific measures to reduce the sensitivity of the African agricultural sector to variations in rainfall and temperature. This could involve the adoption of agricultural techniques that optimize water use

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through the increase and improvement of irrigation systems and the development of grazing areas.

Quantitative estimates of the effects of climate change have improved considerably over the last decade. However, despite a growing body of literature on climate issues in the agricultural sense, a consensus on the potential economic impact of climate change on agriculture is still far from being reached. Depending on the type of climatic variables used, the method of analysis, the geographical zones and the data used, the results are constantly changing.

Most studies have concluded that climate change has had a significant impact on agricultural production in different regions and countries, although the extent of the effect varies according to the type of crop. Among the studies conducted outside Africa, for example Zhang et al, (2017) and those carried out in the African context (Deressa, 2007; Nhemachena et al., 2010; Seo et al., 2009) they have all come to a single conclusion, that climate change has a negative impact on land values or agricultural yields. However, Deschênes & Greenstone (2007) show in their analysis that projected increases in temperature and precipitation will have virtually no effect on yields of the most important crops in the US context. Furthermore, their estimates indicate that climate change will increase annual profits by $1.1 billion, or 3.4%. Furthermore, in the French context, Bareille & Chakir (2023) have shown that warmer summers have a positive impact on French agriculture. Hossain et al (2018) have also shown a positive effect between higher temperatures and crop yields in areas with irrigation systems in Bangladesh. In general, these various findings contradict the widespread view that climate change will have considerable negative consequences for the well-being of the agricultural sector, and at the same time constitute an ambiguity for the fairly intense literature on the subject.

In view of these theoretical and empirical elements, this study poses the question: what is the impact of climate change on cereal production in Sub-Saharan African countries? The overall objective of this study is to measure the impact of climate change on cereal production in Sub-Saharan Africa. From this objective stems the main research hypothesis, which is that climate change has a negative impact on the cereal production in Sub-Saharan African countries. This main hypothesis is followed by two sub-hypotheses. The first would be that the use of information and communication technologies (ICT) through the number of cell phone subscriptions would moderate the negative effects of climate change by increasing cereal production. The second sub-hypothesis would be that irrigation practices would also mitigate the negative impacts of this scourge by increasing cereal production in Sub-Saharan Africa.

To the best of our knowledge, very few studies have been carried out in the literature to measure the impacts of climate change on agriculture in Sub-Saharan Africa. In this context, this work will contribute to the literature in several ways. Firstly, it will fill the gaps in the literature on studies measuring the impact of climate change on agriculture in Sub-Saharan Africa, and will help to clarify the sometimes contradictory results observed to the present. This study will also take into account the use and the development of information and communication technologies in its modeling. The use of ICTs such as the internet and cell phones play an important role in sharing and disseminating messages about climate change from one community to another, particularly among vulnerable people. The ICTs used can encourage the use of sustainable agricultural practices among farmers that help mitigate the effects of climate on local production and protect ecosystems (Adenle et al., 2015; Ospina & Heeks, 2012).

In addition, the use of mobile internet can also help exchange important information on specific issues such as migration, invasive plant diseases, production levels, biodiversity, land distribution and water availability, which may be affected by climate change, particularly among rural and farming communities, reducing their vulnerability to climate variability and change (Adenle et al., 2015). In many cases, cell phones are replacing the messages usually transmitted by traditional radio programs. Cell phone applications provide important services that facilitate access to local agricultural market information in many developing countries (Aker & Ksoll, 2016; Aker & Mbiti, 2010).

This study will also take into consideration the level of human capital in countries, an important catalyst for development in all areas, including agriculture. Human capital contributes to the learning, application and dissemination of technical knowledge. It influences the farmer's ability to adapt new technologies to specific conditions, such as changing demand, geographical restrictions and environmental problems (Djomo & Sikod, 2012; Reimers & Klasen, 2013).

The rest of this study is as follows: section 2 presents the literature review. The methodology and data sources used are presented in session 3. The results are presented and interpreted in section 4. Section 5 is devoted to a discussion of the results. Finally, the last section presents the conclusion, policy implications and limitations of this study.

1. Literature review

Specialists, economists and policy-makers around the world are taking a keen interest in the negative impacts of climate change and its variability on agriculture. As a result, a multitude of empirical studies have been carried out, using different methodologies to assess the extent to which climate change is a threat to agricultural production. Among these different approaches, three stand out as the most widely discussed in the literature. These are the Ricardian model developed by Mendelsohn et al (1994), the model based on the production function and the last approach based on crop simulation or calibration.

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1.1 The Ricardian approach

The Ricardian method considers the relationship between land income or land value and agroclimatic variables, using cross-sectional information (Mendelsohn et al., 1994). The main advantage of the Ricardian method is that it captures farmers' adaptive actions that can influence land values. This approach has served as a basis for analysis by several authors. Vaitkeviciute et al. (2019) in the context of European FADN member regions, Martin & Vaitkeviciute (2016) , in the context of the 705 communes of the Côte d'Or, Bareille & Chakir (2023) in the context of data from repeated transactions on the same plots in France, Hossain et al. (2018) in the context of Bangladesh, Nguyen & Scrimgeour (2022) in the context of Vietnam. Most of these studies reveal a more or less positive impact of climate change on agriculture, especially (Bareille & Chakir, 2023; Hossain et al., 2018; Vaitkeviciute et al., 2019) . For example, with data from Bangladesh, Hossain et al., (2018) have shown the existence of a positive effect between climate change and net agricultural income. Their results show that any increase of 1 mm/month in rainfall and 10°C in temperature will lead to an increase of around 4 to 15 USD in net crop income per hectare.

In the African context, authors such as Deressa, (2007); Kurukulasuriya et al. (2006); Nhemachena et al., (2010) and Seo et al. (2009) have used it to measure the impact of climate change on agriculture. The results of these empirical studies revealed that agricultural production declines as a result of climate fluctuations. Deressa (2007) used the Ricardian model to show that in Ethiopia, climatic variables have a significant impact on farmers' net income. Nhemachena et al (2010) using data from 11 countries in East, West, North and South Africa, show that net farm income is generally negatively affected by hotter and drier climates. Kurukulasuriya et al, (2006) have also shown in 11 African countries that incomes decrease with warming for crops grown in arid zones, while incomes increase for irrigated crops, which are located in relatively cooler parts of Africa and are protected from the effects of warming by irrigation. For them, the final effects will also depend on rainfall trends, as revenues for all farm types increase with rainfall.

1.2 Production function approach

More recently, the use of the production function approach for panel data and time series analysis has grown rapidly. This approach has been adopted by Deschênes & Greenstone, (2007) in the context of American agriculture. Using annual data on climate variables (precipitation and temperature), they showed that climate change will lead to a $1.1 billion (2002$) or 3.4% increase in annual profits for the agricultural sector. Furthermore, the analysis

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indicates that predicted increases in temperature and precipitation will have virtually no effect on yields of the most important crops (i.e. corn, soybeans and wheat for seeds).

In the African context, many studies have also applied it. This is the case of authors such as (Abdi et al., 2022; Barrios et al., 2008; Blanc, 2012; Nonvide et al., 2023; Ochou & Quirion, 2022; Yobom & Le Gallo, 2022). Blanc (2012) started from a distinction between agriculturally favorable and unfavorable countries and shows that, in general, there is a significant impact of weather conditions on yields of the four most commonly harvested crops in sub-Saharan Africa. More specifically, changes in rainfall had a greater impact on millet and sorghum yields in countries that are favorable to agriculture than those that are less so. The work of Barrios et al. (2008) have shown that climate change has had significant effects on total agricultural production in Sub-Saharan African countries, but not in other developing countries. Abdi et al (2022) have shown in the context of East African countries that rainfall and carbon emissions have favorable and significant long-term effects on cereal crop production, while average temperatures have negative repercussions on cereal production, even if their short-term impacts are negligible. In addition, Yobom & Le Gallo, (2022) based on data from Sahelian countries, have shown that the average temperature and rainfall of the growing season play a very important role in the production of the five most produced cereals in this zone and in the net agricultural production index. Their results also show that the effects of temperature and rainfall are heterogeneous across countries and agro-ecological zones.

1.3 Calibration-based approach

This approach has been used by authors such as Lokonon et al (2019) and Torriani et al. (2007). Indeed, Lokonon et al. (2019) based on the bioeconomic modeling and calibration approach, found that the impacts of climate change in West African countries are not uniform across countries and agricultural zones, highlighting disparities across geographical units. However, they did formally show that cropland and crop production in West African countries are sensitive to climate change.

2. Methodological approach

The aim of this section is to present the methodological approach, highlighting the estimation techniques, the various diagnostic tests, the descriptive statistics of the variables and the data sources used.

2.1 Empirical model specification

According to the authors Albers et al (2017) **;** Barrios et al. (2008) and Yobom & Le Gallo, (2022)**,** this study will use a Cobb-Douglas production function to measure the impact of climate change on the production of four key cereals: maize, millet, rice and sorghum in Sub-

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Saharan Africa. This study focuses on the production of these cereals, as they are the most widely consumed in Africa. They are used in the form of flour for consumption or eaten directly in their fresh state (Yobom & Le Gallo, 2022). In addition, analysis of the production of these cereals is necessary, because due to their level of poverty, farmers in sub-Saharan Africa produce for their own subsistence Lokonon et al. (2019) and because the level of production of these cereals depends on climatic conditions (Yobom & Le Gallo, 2022). Moreover, according to FAO data, they are among the leading crops in terms of total harvested area and value of agricultural production in the region.

Furthermore, according to Lokonon et al, (2019) and Yobom & Le Gallo, (2022) this study will also focus on average temperatures and average rainfall from April to November, which are assumed to be the main climatic factors prevailing during the vegetative crop development stages (Lokonon et al., 2019). Calculations of average rainfall and temperature obviously go back to the work of Mendelsohn et al. (1994) who used daily data to obtain monthly data for four months (January, April, July and October).

With this in mind, our dependent variable *agricultural production (Y)* will be regressed on the climate variables and on a set of control variables for each cereal.

The production function equation for each specific cereal can be specified as follows:

$$lnY_{it} = \alpha_0 + \alpha_1 Ln(Prec)_{it} + \alpha_2 Ln(Temp)_{it} + \alpha_3 Ln(Prec * Temp)_{it} + \alpha_4 Ln({Force_{trav}}_{it}) + \alpha_5 \mathrm{Ln}\left({Conso_{fert}}_{it}\right) + \alpha_6 \mathrm{Ln}\left({Ter_{arab}}_{it}\right) + \alpha_7 Ln(abon\_tel)_{it} + \alpha_8 {Taux_{alph}}_{it} + \alpha_9 Ln\left(Ter_{irrig}\right)_{it} + \alpha_{10} Livstock_{it} + \mu_i + \varepsilon_{it}$$

(1)

With Y_{it} the total production of the cereal for country i at a given time t. $Prec_{it}$ and $Temp_{it}$ respectively represent average rainfall and temperature during the growing period. $Prec * Temp_{it}$ is set for the cross effect between precipitation and temperature. $Force\_trav_{it}$ is labor force ; $Conso\_fert_{it}$ represents fertilizer consumption; Ter_arab_{it} corresponds to arable land; $Taux\_abon_{it}$ is set for the number of cell phone subscriptions used to capture the level of development of information and communication technologies, $Taux\_alph_{it}$ is set for the secondary school enrolment rate to capture the development of human capital in the population and finally Ter_irrig_{it} which provides information on land equipped with irrigation techniques, $Livstock$ characterizes the number of livestock per agricultural area; μ_i is the unobserved specific effect of country i and ε_{it} the error term.

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2.2. Estimation techniques

To estimate the effects of climate change on agricultural variables (total production or yield), in the presence of panel data, researchers often choose between a fixed-effects model and a random-effects model. A fixed-effects model controls for unobservable variables by including fixed effects that may be time- or group-specific in the regression specification. The random-effects model is a special case of the fixed-effects model in which the group-specific effects are uncorrelated with the independent variables. Specifically, the random effects model does not include the group fixed effect; instead, it assumes that the error term is a group-specific component (Blanc & Schlenker, 2017; Greene, 2000).

Preference in the literature Blanc & Schlenker (2017); Deschênes & Greenstone, (2007) and Yobom & Le Gallo (2022) has been to estimate climatic impacts on agricultural variables using the group fixed effects model since weather averages are correlated with many other explanatory variables. Group fixed effects will absorb any confounding effects that might be caused by unobserved factors that are constant over time within each group.

2.3.Robustness tests

2.3.1. Hausman test

First of all, it was useful to run the Hausman test for each of our regressions following each cereal. This test enables us to make an informed decision on which of the two models to consider. A probability of less than 5% means that the fixed-effects model should be considered, rather than the random-effects model in which the country-specific fixed effects are correlated with the explanatory variables.

2.3.2. Tests for residual normality, error autocorrelation, cross-sectional correlation and heteroscedasticity

In this study, group-level heteroscedasticity, cross-sectional correlation and error autocorrelation were tested within the data. Group-level heteroscedasticity was tested using the Wald test modified by Baum (2001) within-panel error autocorrelation was tested using the Wald test proposed by Wooldridge (2010) and cross-sectional correlation was tested using the Pesaran test proposed by (Pesaran, 2004). The *Skewness/Kurtosis* normality test of (Jarque & Bera, 1987) and the Shapiro-Wilk test proposed by (Shapiro & Wilk, 1965) also were tested. Table A3 in the appendix shows the results of the modified Wald test, the Wooldridge test and the Pesaran test, which indicate the existence of heteroscedasticity, cross-sectional correlation and error autocorrelation within the data, and a lack of normality.

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2.4. Descriptive statistics and data sources

The following tables (1&2) show the results of the descriptive statistics. The results in Table 1 show that maize is the most widely produced cereal in Sub-Saharan Africa, at least as far as the countries considered in this study are concerned. It is followed by rice, sorghum and millet.

Table 1: Descriptive statistics for cereal production variables

Dependent variables				
Variables	Average	Standard deviation	Minimum	Maximum
Total maize production in tonnes	1698356	2635435	979	1.76e+07
Total millet production in tonnes	421784.2	1019145	387.4	9064000
Total rice production in tonnes	500160.8	1116043	400	1.09e+07
Total sorghum production in tonnes	591030.5	1381573	0	9866000

Source: author's results

These data on cereal production come from the Food and Agriculture Organization of the United Nations (FAO Stat) database. Other variables in our analysis also come from this source, namely land equipped with irrigation techniques, and the number of livestock per unit area. Variables such as total labor force, fertilizer consumption, arable land, number of cell phone subscriptions and secondary school enrolment come from World data indicators (WDI). Finally, our climate variables come from the World Bank website.

Table 2: Descriptive statistics for independent variables

Independent variables				
Variables	Average	Standard deviation	Minimum	Maximum
Average precipitation in mm	100.2583	71.73355	7.78375	365.2075
Average temperature in °C	25.23571	3.794978	14.9675	32.165
Workforce (total)	9359572	1.16e+07	303949	7.34e+07
Fertilizer consumption in kg per hectare	471.5646	274.2029	1	947
Arable land in hectares	5662226	6690269	161000	3.69e+07
Number of cell phone subscriptions	9879671	2.26e+07	0	2.22e+08
Land equipped with irrigation (1000 ha)	142.5938	286.2199	0.5	1670
Secondary school enrolment	30.81475	18.4493	4.72083	111.802
Number of livestock (Units per agricultural area)	0.25468	0.19306	0.02	1.16

Source: author's estimation results

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3. Estimation results and interpretation

We have carried out a preliminary analysis using ordinary panel data models, namely the fixed-effects (FE) model and the random-effects (RE) model. However, it is important to check for multicollinearity between the independent variables. Indeed, if the explanatory variables are correlated with each other, the estimate of the panel data model will be overestimated and, consequently, the results will be biased. We therefore report a correlation matrix in Table A1 in the appendix of this document. A very high coefficient close to 1 or -1 is synonymous with a high correlation between the variables and therefore the presence of multicollinearity. Based on the results of this matrix, we can conclude that the variables do not present a multicollinearity problem.

According to the results of the fixed-effect (FE) model presented in Table 3, for all cereals, both precipitation and temperature have a negative effect on production, except for rice, where there is no effect of climate change on its production. For the random effect model (RE), the signs of the coefficients of the climate variables confirm those obtained previously. The results of the random-effect model are presented in Table A2 in the Appendix. Based on these two models, we can conclude that climate change has a negative effect on cereal production in Sub-Saharan Africa. Furthermore, the results of both models (FE&RE) show that the cross effect between precipitation and temperature is positive on the production of these three cereals (maize, millet and sorghum). This new result would suggest that increased rainfall is a major factor in mitigating the negative effects of rising temperatures on agriculture in Sub-Saharan Africa.

The majority of the other control variables confirm the good sign on the production of the various cereals, namely the number of cell phone subscriptions, the number of livestock per agricultural area, arable land, and the secondary school enrolment rate for maize and rice.

It has also been noted that most researchers have directly interpreted the results of fixed- or random-effects models without performing the diagnostic tests provided for in the literature, for example (Yobom & Le Gallo, 2022). In this study, the specification test of Hausman (1978) is applied to each of the four cereal regressions to choose between the FE and RE models. In the Hausman test, the null hypothesis indicates that the random-effects model is the most appropriate compared with the alternative hypothesis. The null hypothesis is rejected at a significance level of 5% for all cereals (millet, rice, sorghum) except maize, where the null hypothesis cannot be rejected. The results of the test indicate that, overall, the FE model is appropriate for the present study.

However, this difference in results between fixed- and random-effects models on certain control variables such as labor input and fertilizer consumption may be explained by the fact that FE and RE models suffer from problems of group-level heteroscedasticity, autocorrelation or serial correlation. It is therefore necessary to carry out diagnostic tests to ensure that the model is robust. The results of the various diagnostic tests are presented in Table A3 in the Appendix.

The results in Table A3 show that for the Wooldridge (2010) test, the null hypothesis of no serial correlation is rejected at the 1% significance level. This reveals that the fixed-effects model suffers from the serial correlation problem for each of the regressions. Pesaran's test (2004) shows the presence of cross-sectional dependence for millet, rice and sorghum, except for maize. For the Jarque-Bera and Shapiro-Wilk normality tests, probabilities below 1% imply rejection of the null hypothesis of residual normality. Finally, for heteroscedasticity at group level, the Wald test modified by Baum (2001) was applied. The null hypothesis of group-level homoscedasticity is rejected at a significance level of 1%. The result of the Wald test indicates the presence of group-level heteroscedasticity in the model. Thus, the diagnostic tests conclude that the FE model presents problems of serial correlation, cross-sectional correlation and group-level heteroscedasticity. To resolve these problems, the standard FGLS model was applied. The FGLS model is said to resolve group-level heteroscedasticity, cross-sectional correlation and within-panel autocorrelation, to guarantee more accurate results. This model has already been used in the literature on the impact of change on agriculture by many authors (Ogundari & Onyeaghala, 2021; Wu et al., 2021).

Table 3: Estimation results for Fixed Effect (FE) models

VARIABLES	Log (Corn production)	Log (Millet production)	Log (Rice production)	Log (Sorghum production)
Ln (Precipitation)	-5.500***	-8.491***	-2.068	-11.17***
	(1.740)	(1.702)	(1.979)	(1.698)
Ln (Temperature)	-9.802***	-10.13***	-1.945	-15.45***
	(2.581)	(2.525)	(2.936)	(2.521)
Ln (Precipitation*Temperature)	1.841***	2.851***	0.657	3.603***
	(0.553)	(0.541)	(0.629)	(0.540)
Ln (Number of mobile subscriptions)	0.0263***	0.0364***	-0.0234**	0.0362***
	(0.0102)	(0.00997)	(0.0116)	(0.00997)
Secondary school enrolment	0.0101***	0.000596	0.00736***	-0.00640***
	(0.00212)	(0.00207)	(0.00241)	(0.00207)
Number of cattle per unit of farmland	0.707***	1.056***	0.832***	0.618**

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	(0.269)	(0.263)	(0.306)	(0.266)
Ln (Land with irrigation system)	-0.135***	-0.00464	0.191***	-0.0224
	(0.0514)	(0.0503)	(0.0585)	(0.0506)
Ln (Work force)	0.538***	-1.346***	1.429***	-0.380**
	(0.173)	(0.169)	(0.197)	(0.170)
Ln (Arable land)	0.690***	1.074***	0.627***	0.798***
	(0.132)	(0.129)	(0.150)	(0.129)
Ln (Fertilizer consumption)	0.0251	-0.0498***	0.0312	-0.0190
	(0.0190)	(0.0185)	(0.0216)	(0.0186)
Constant	23.60***	45.14***	-15.03	53.27***
	(8.773)	(8.585)	(9.981)	(8.574)
Comments	826	826	826	819
R-squared	0.543	0.170	0.573	0.182
Number of countries	30	30	30	30

Standard deviation in brackets

*** p<0.01, ** p<0.05, * p<0.1

Source: author's estimation results

The results of the FGLS model in Table 4 below show that the number of cell phone subscribers has a positive impact on maize and rice production, while the impact is insignificant for millet and sorghum. Secondary school enrolment has a positive impact on maize production. However, for rice, millet and sorghum, the impact is negative and significant, which seems counter-intuitive. The number of cattle per unit of farmland also has a positive impact on maize, millet and sorghum production, while the impact is negative for rice production. The results also show that irrigation has a positive impact on the production of all cereals. As for labor power, the results reveal a positive impact on maize and rice production, while the impact is significant and negative for millet and sorghum. Arable land also has a positive impact on maize, millet and sorghum production, while the impact is negative for rice. The results also show that there is no effect of fertilizer use on cereal production.

With regard to climatic variables, the results show that average rainfall and average temperature have a negative effect on maize production. However, temperature is beneficial for millet and rice production. Indeed, a positive effect is obtained between temperature and millet and rice production. The results of the FGLS model show no effect of climatic variables on sorghum

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production. On the other hand, the results show that the cross effect between rainfall and temperature is positive for maize production.

Table 4: FGLS model results

VARIABLES	Log (Corn production)	Log (Millet production)	Log (Rice production)	Log (Sorghum production)
Ln (Precipitation)	-6.414***	-1.117	0.850	-1.291
	(0.933)	(0.860)	(0.947)	(1.110)
Ln (Temperature)	-9.878***	3.474***	7.155***	0.480
	(1.233)	(1.110)	(1.164)	(1.403)
Ln (Precipitation*Temperature)	2.027***	0.435	-0.106	0.436
	(0.292)	(0.270)	(0.293)	(0.344)
Ln (Number of mobile subscriptions)	0.0283***	0.00437	0.0667***	-0.00463
	(0.00785)	(0.0114)	(0.0138)	(0.0129)
Secondary school enrolment	0.00549***	-0.0151***	-0.00553**	-0.00553**
	(0.00162)	(0.00232)	(0.00254)	(0.00241)
Number of cattle per unit of farmland	0.224*	1.358***	-1.028***	2.239***
	(0.117)	(0.180)	(0.287)	(0.190)
Ln (Land with irrigation system)	0.0474**	0.267***	0.0882**	0.103**
	(0.0236)	(0.0393)	(0.0420)	(0.0447)
Ln (Work force)	0.682***	-0.540***	1.088***	-0.226*
	(0.0728)	(0.101)	(0.120)	(0.120)
Ln (Arable land)	0.472***	1.399***	-0.513***	1.368***
	(0.0743)	(0.103)	(0.113)	(0.110)
Ln (Fertilizer consumption)	0.0172	-0.00994	0.0234	0.0199
	(0.0118)	(0.0156)	(0.0155)	(0.0142)
Constant	25.99***	-14.70***	-23.40***	-8.069*
	(3.968)	(3.541)	(3.875)	(4.563)
Comments	826	826	826	819
Number of countries	30	30	30	30

Standard deviation in brackets

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: author's estimation results

4. Discussion of results

The positive effect of the number of cell phone subscriptions on maize and rice production corroborates the work of Chavula (2014) and (Eyike Mbongo & Djoumessi, 2024). Chavula (2014) has shown that in Sub-Saharan Africa, ICTs help agricultural researchers and experts to adopt improved farming practices and disseminate them to farmers. They provide agricultural information relevant to farmers, such as farming techniques, commodity prices and weather

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forecasts. The use of ICTs, particularly mobile technologies, helps agricultural producers, who are often unaware of commodity prices on adjacent markets and rely on information provided by traders to determine when, where and at what price to sell their products, to have relevant and timely information in this respect. However, this result runs counter to Onyeneke et al. Onyeneke et al (2023) who in their analysis of the impact of ICTs especially the number of cell phone subscriptions on agricultural production find a negative relationship between the two variables. According to these authors, cell phone network coverage in Africa is low and mainly located in urban areas where agricultural production is rarely practiced. Moreover, they argue that even rural dwellers with cell phone subscriptions do not necessarily use their cell phones to obtain information on agricultural production, but rather to communicate with family and friends. These tools can even be a source of distraction for these farmers. This is where education has an important role to play.

The positive effect of education, which is an important indicator of human capital and captured by the secondary school enrolment rate, on maize production can be explained by the fact that it may enable farmers and others in the surrounding area to adopt new production technologies. Indeed, more educated farmers are not only more likely to adopt modern production technologies and inputs than less educated farmers, but also apply them more effectively. They can easily adopt seeds that are more resistant to the negative effects of climate change. This result is in line with Mafie (2022) who, using microeconomic data from Tanzania, was able to show that education is a catalyst for reducing the negative effects of climate change on agricultural productivity. Chavula (2014) has also shown, using data from Sub-Saharan African countries, that education is a major factor in improving agricultural production. On the other hand, the negative effect observed on millet, rice and sorghum production, which is counter-intuitive, could be explained by the fact that in Sub-Saharan Africa, those with secondary education are people who want to enter the tertiary sector at all costs and are not motivated to do agricultural work. What's worse, these people are leaving the countryside for the towns, which is creating a shortage of agricultural labour.

The positive effect of labor force on maize and rice production corroborates the work of Yobom & Le Gallo (2022) who found that in Sahelian countries, labor power has a positive impact on maize, millet and sorghum production. This result would stem from the fact that sub-Saharan Africa is one of the world's most demographically dynamic regions, with the youngest population and a large majority of its population engaged in agriculture (over 60% according to statistics), especially as 89% of cultivated land is hand-cultivated (Blanc, 2012).

The positive impact of livestock numbers, which include the total number of cattle, sheep and goats, on maize, millet and sorghum production is in line with that of (Yobom & Le Gallo, 2022). This result can be explained by the fact that in Sub-Saharan Africa, the rearing of these animals produces manure that is used by farmers to grow crops. The existence of these manures could even give farmers more incentive to develop crops on the least fertile arable land set aside.

The positive effect of irrigation on maize, millet and rice production corroborates the work of Calzadilla et al, (2013) and (Djoumessi, 2021). Calzadilla et al. (2013) have shown that the expansion of irrigated areas in Sub-Saharan Africa, allows farmers to achieve higher yields per hectare. The result is higher total agricultural production and lower prices for agricultural products.

Arable land has a positive effect on maize, millet and sorghum production, while the impact is negative for rice. The positive effect corroborates the work of Kareem (2018) who has shown that arable land is a key factor in the development of agriculture in Sub-Saharan Africa. More specifically, the author showed that investors with agricultural intent invest in countries where arable land is available and fertile. On the other hand, if we assume that arable land is unoccupied space, an increase in arable land must have a negative impact on production, which could explain the negative sign between this variable and rice production.

Fertilizer consumption has no effect on cereal production. This result is less surprising given that Lokonon et al. (2019) have already recognized in their work on West African countries that the use of technology and fertilizer is not widespread and remains marginal.

As far as climatic variables are concerned, the negative effect of precipitation on maize production is in the opposite direction of (Blanc, 2012; Yobom & Le Gallo, 2022). Indeed, Yobom & Le Gallo (2022) found a positive effect between average rainfall over the growing period and maize production. Moreover, with annual data, Blanc (2012) showed that rainfall has a positive effect on maize production in Sub-Saharan Africa.

For temperature, the contrasting effect found, (positive on rice and millet production and negative on maize production), corroborates the work of Yobom & Le Gallo (2022) who found almost the same effects. In fact, these authors also found a positive effect of mean temperature over the growing season for the production of certain cereals (millet and sorghum) in Sahelian countries, and a significant negative effect for maize and rice. Lokonon et al. (2019) also found a positive effect between mean temperature and rice and millet production in West African countries. The fact that, in the FGLS model, climate variables have no impact on sorghum production is in line with the findings of Lokonon et al. Deschênes & Greenstone, (2007). In the context of American agriculture, these authors have shown with annual data that predicted increases in temperature and precipitation will have virtually no effect on yields of the most important crops (i.e. corn, soybeans and wheat for seeds).

The positive effect of the combination of precipitation and temperature on maize production, goes in the opposite direction of Blanc (2012) who found that the combination had a negative effect on maize production, and is in line with (Fezzi & Bateman, 2015). According to, Fezzi & Bateman (2015), higher temperatures only increase land value (and therefore production) if rainfall is sufficient to prevent the risk of drought. They were able to show that increases in precipitation are valuable assets for reducing the negative effects of temperature rises.

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Conclusion

Climate change is causing considerable upheaval for cereal crops worldwide. Understanding the impact of climate change on cereal production has therefore become crucial to supporting the world's major agricultural regions in adopting new technologies to improve the resilience of this production. This will not only improve yields, but also ensure global food security at the same time. The aim of this study is to measure the impact of climate change on the production of the four most widely consumed cereals in Sub-Saharan Africa. It focused on 30 Sub-Saharan African countries over the period 1990 to 2022. The study also considered average rainfall and temperature between April and November, and a range of other control variables.

In order to arrive at the results, the study made use of several econometric techniques. It used standard panel data models, namely the fixed-effects model, the random-effects model and the FGLS model, after several diagnostic and robustness tests.

Econometric results from the FGLS model show that average rainfall and temperature over the growing period have a negative effect on maize production. As for the other cereals (millet and rice), according to the results, only temperature has a positive effect on their production. We can confirm that climatic variables have an ambiguous effect on the production of the various cereals.

The hypothesis that the use of information and communication technologies would mitigate the negative effects of agricultural change has been verified. We found evidence that increased use of this technology improved maize and rice production. We also found evidence that irrigation practices, the human capital of the population through the secondary school literacy rate, and the number of livestock per unit of farmland are positive elements that improve cereal production. On the other hand, the use of chemicals has no effect on cereal production in Sub-Saharan Africa.

In view of these results, we believe it would be necessary for the countries of Sub-Saharan Africa to invest massively in irrigation projects, and to step up their efforts to develop human capital through the creation of various educational and vocational training centers. It would also be important for these countries to reduce taxes and customs duties on cell phone imports, and to adopt low-cost national communication policies to make mobile phones more accessible to the vast majority of the population, even the poorest. These countries must also promote innovation projects.

A more important limitation of this study is that the results obtained for certain crops were contrary to expectations. In fact, this is a problem often encountered in panel data analysis and already encountered in the literature, despite the necessary diagnostic tests.

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Appendix

List of countries considered in this study.

Angola, Benin, Burundi, Burkina-Faso, Central African Republic, Cameroon, Chad, Côte d'Ivoire, Democratic Republic of Congo, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Uganda, Zambia, Zimbabwe,

Table A1: Results of the correlation matrix between variables

	LnPréci	LnTemp	Ln_mobil	Tx_school	Livestock	Ln_irrigat	Ln_labor	Ln(Terr_arab)	Ln(Co
LnPréci	1								
LnTemp	0.2601	1.							
Ln_mobil	-0.0454	-0.0363	1						
Tx_school	-0.0092	-0.3345	0.5278	1					
Livestock	0.3299	0.0634	0.1764	-0.0351	1				
Ln_irrigat	-0.4628	-0.1997	0.3210	0.3562	-0.1304	1			
Ln_labor	-0.1056	-0.2901	0.3777	0.2585	0.0315	0.5882	1		
Ln(Terr_arabl)	-0.1616	-0.1059	0.2887	0.1599	-0.0260	0.5944	0.9023	1	
Ln(Conso_fert)	-0.1746	-0.1456	0.2136	0.3043	-0.0663	0.4357	0.1703	0.0642	1

Source: author's estimation results

Table A2: random model results

VARIABLES	Log (Corn production)	Log (Millet production)	Log (Rice production)	Log (Sorghum production)
Ln (Precipitations)	-5.415***	-6.433***	-1.045	-7.926***
	(1.612)	(1.602)	(1.906)	(1.586)
Ln (Temperature)	-10.17***	-5.493**	3.152	-9.011***
	(2.208)	(2.179)	(2.604)	(2.148)
Ln (Precipitation*Temperature)	1.787***	2.163***	0.422	2.545***
	(0.510)	(0.507)	(0.603)	(0.502)
Ln (Number of mobile subscriptions)	0.0235**	0.00915	0.00500	0.0216**
	(0.00917)	(0.00911)	(0.0108)	(0.00908)
Secondary school enrolment	0.00953***	-0.00403**	0.0109***	-0.00873***
	(0.00201)	(0.00201)	(0.00238)	(0.00200)

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Ln (Number of cattle per unit of farmland)	0.619**	0.899***	1.025***	0.768***
	(0.256)	(0.255)	(0.303)	(0.256)
Ln (Land with irrigation system)	-0.107**	0.0569	0.117**	0.0216
	(0.0485)	(0.0483)	(0.0574)	(0.0483)
Ln (Workforce)	0.641***	-0.883***	0.862***	-0.225
	(0.147)	(0.146)	(0.174)	(0.144)
Ln (Arable land)	0.655***	1.300***	0.419***	0.941***
	(0.123)	(0.122)	(0.145)	(0.121)
Ln (Fertilizer consumption)	0.0289	-0.0566***	0.0435*	-0.0206
	(0.0188)	(0.0189)	(0.0223)	(0.0189)
Constant	24.03***	20.64***	-20.87**	28.82***
	(7.390)	(7.280)	(8.710)	(7.175)
Comments	826	826	826	819
Number of countries	30	30	30	30

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: author's estimation results

Table A3: Table showing the summary results of the various tests.

	Test				Normality test	
Variables	Hausman	Wooldridge test (2010)	Wald Modified (2000)	Pesaran (2004)	Shapiro-Wilk	Jarque-Bera
Corn	chi2(13) = 8.86 Prob>chi2 = 0.4499	chi2(435) = 6.763 Pr = 0.0145	chi2 (30) = 9578.30 Prob>chi2 =0.0000	Stat =- 1.258 Pr = 0.2084	Z= 9.255 Prob>z= 0.00000	chi2(2) = - Prob>chi2= 0.000
Mil	chi2(13) = 66.51 Prob>chi2 = 0.0000	chi2(435) = 2.639 Pr = 0.1151	chi2 (30) = 9390.03 Prob>chi2 = 0.0000	Stat= 2.517 Pr = 0.0118	Z= 4.074 Prob>z= 0.00000	chi2(2) = 8.59 Prob>chi2= 0.0136
Rice	chi2(13) = 301.27 Prob>chi2= 0.0000	chi2(435) = 36.655 Pr = 0.000	chi2 (30) = 66469.19 Prob>chi2 = 0.0000	Stat= 7.723, Pr = 0.0000	Z= 7.874 Prob>chi2= 0.000	chi2(2) = 49.92

						Prob>chi2= 0.0000
Sorghum	chi2(13) = 48.88 Prob>chi2= 0.0000	chi2(435) = 12.598 Pr = 0.0013	chi2 (30) = 2119.01 Prob>chi2 = 0.0000	Stat= 2.059 Pr = 0.0395	Z= 6.232 Prob>chi2= 0.000	chi2(2) = 70.25 Prob>chi2= 0.000
Conclusions	The fixed-effect model is preferred except for corn	Serial correlation problem for cereals except millet	Heteroscedasticity problem for the four cereals	Transverse dependency problem except for corn	Lack of normality	Lack of normality

Source: author's estimation results