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Modelling climate change impact and mitigation actions: A case study of rice productivity in West Africa based on panel data analysis

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This paper investigated how climate change can affect paddy rice productivity and proposed a mitigation measure that may be undertaken. The analysis first explored the potential impacts of climate variables on rice yields by using panel data covering the period 1980 to 2016 for seven countries members of the West African Economic and Monetary Union (WAEMU). It then went on to calculate the investments needed in Research and Development (R&D) for developing new crop varieties technologies by applying the methodology developed by World Bank (2010). Results indicated the growth of rice yields was positively related to the level of technological progress, the rainfall or quantity of water, and amount of seedlings. The concentration level temperature and the mass of carbon dioxide emitted throughout rice cultivation appeared to affect negatively the growth of rice yields. From the estimation of fixed-effects model, the findings showed the existence of specificities (heterogeneity) among the underlying countries that influenced positively rice production in the study area. After all, the aggregate impact of climate change on paddy rice productivity was found to be negative in WAEMU area. From the application of Word Bank methodology, it was recommended to all the countries, in particular, Benin, Burkina-Faso and Niger to increase constantly their annual (R&D) spending throughout the period 2017 to 2050. In consideration of the negative impact of climate variables, the study proposed the development of new rice varieties that could withstand temperature, and a rigorous management of postharvest cropland enabling the reduction of negative externalities due to carbon dioxide emissions.

Key words: Rice productivity, climate change, mitigation, panel data analysis.

INTRODUCTION

For a long time, agricultural sector has been facing so many restraints that hindered its ability to furnish sufficient and affordable quantities of food, as the result of a growing population, rising demands, and fickle diets. Meanwhile, climate change was generating extra pressure on agricultural activities and its effects were

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expected to be more striking in the future (Foresight, 2011; Lobell et al., 2011). In addition to changing on agricultural productivity, many other impacts were observed (Bryngelsson et al., 2016; Elofsson et al., 2016), including modification in the timing of seasonal occurrences (e.g., earlier flowering of plants). Nevertheless, climate change may also profit agricultural activities in certain areas or countries. Actually, future effects may vary depending on related policies and social development. Accordingly, policies addressing climate change should be oriented either to reduce the sources of greenhouse gases (GHG) (mitigation) or to adjust natural or human systems (adaptation) in response to expected externalities. Today, there exists a consensus between emitters that policies regarding this matter should focus more on mitigation actions. Obviously, whether the outcome of these agreements is attained or not, adaptation measures should be quickly designed in order to diminish the negative impacts on food availability, particularly, in countries which suffer from food security (OECD, 2015; Weldegebriel and Gustavsson, 2017). In that context, Valin et al. (2013) put forward that in developing countries, yield increase could likely mitigate some agriculture-related emissions growth. They also advised the combination of productivity increases in both crop and livestock cultivation in order to exploit mitigation and food security co-benefits. However, the outcome was sensitive to the technological path and which factor benefits from productivity gains. For Sommer et al. (2013), only adaptive changes in sowing dates, cultivated land, farming techniques and in inputs might lead to further yield increases. Their statement followed the fact that yields responses to climate change would likely be related to agro-ecological zones, cultivable land types, crop varieties, agronomic management and future anticipations. Furthermore, Jayne et al. (2014) emphasized the importance to anticipate more the implications of rapidly changing land due to global climate change, while Kjellstrom et al. (2009) stressed the necessity to prevent likewise the consequences on health and labor productivity. Otherwise, some countries such as those members of the Economic Community of West African States (ECOWAS) may become dependent on food imports outside their geographical space (Egbendewe et al., 2017).

As matter at stake, rice foodstuff has drawn attention of previous researches like Tazhibayeva and Townsend (2012), as one of staple crops and main agricultural commodities with regard to human feeding worldwide. Specifically in a large part of the West African Economic and Monetary Union (WAEMU), rice ploughing requires in general high rainfall or ample irrigation, particularly for the most grown variety named paddy rice. As a matter of fact, rice could be grown practically on any field (including a steep hill or mountain) provided that an effective water management system was established. In case of dissatisfaction to this latter, long term changes in means and standard deviations of the climatic variables in a country may have serious impacts on the productivity of rice in different regions (Iqbal and Siddique, 2014). In this context, Zannou et al. (2018) proposed that the technical efficiency of irrigated rice seed should be taken into account when seeking high economic advantage, consistently with the study of Narain et al. (2011) that highlighted the importance of improved crop technologies. Mishra et al. (2018) found that adopting organic rice farming practice would perhaps lead to lower yield, but that loss might be offset by increases in both ecological benefits such as improvement in livelihood and economic gains like rising in prices for producers. However, rice producers may face a lot of challenges in marketing, but not only due to low productivity, but mostly owing to the high competition they do affront with cheaper imported rice, as well as government policy restrictions (Atera et al., 2018).

On the basis of the background above, this study sought mainly to understand the climate and paddy rice production nexus, and further, intended to estimate the costs for potential mitigation actions to climate change in seven countries of the WAEMU over the period 1980 to 2016. In this respect, the present research did raise a fundamental question; “how are changes in climate variables linked to paddy rice productivity?” To address this question, the aim of this study did stand twofold: (i) Analyzing how climate change may affect paddy rice yields; (ii) Providing estimates of the magnitude of the mitigation costs for the countries.

Modelling and data description

Theoretical model for crop yields simulation

Generally, crop yields are simulated based on climate variables (temperature, precipitation, and CO_2 concentration levels), soil types, and management or technology types. In the context of this research, the yield function used was drawn from previous research (Gornott and Wechsung, 2016) and could be expressed as:

$$\mathrm{Y_{it}} = \mathrm{Z_{it}}(T_{it}^{\alpha})(P_{it}^{\beta})(CO_{2}{}_{\mathrm{it}}^{\gamma})(S_{it}^{\delta}) \quad (1)$$

or in logarithmic terms:

$$\log(\mathrm{Y_{it}}) = \log(\mathrm{Z_{it}}) + \alpha\log(T_{it}) + \beta\log(P_{it}) + \gamma\log(CO_{2_{\mathrm{it}}}) + \delta\log(S_{it}) \quad (2)$$

where i and t are respectively the individual or country index and time index; Z_{it} represents the technological progress; T_{it} is the monthly mean temperature; P_{it} is the monthly mean precipitation; CO_{2it} is the carbon dioxide concentration in the atmosphere at the time t; S_{it} gathers characteristics relating to soil or management/technology type; and α, β, γ, δ represent the parameters of the model.

Method of calculating future R&D adaption costs

In order to estimate the annual spending in agricultural R&D due to

Table 1. Assumed multipliers of historical growth rates of agricultural R&D.

Period	2017-2020	2021-2030	2031-2040	2041-2050
g_c (%)	8	7	6	5

Source: World Bank (2010).

Table 2. Variable definitions and data sources.

Variable	Definition	Sources
YIELD	Amount of paddy rice production per hectare, in kg/ha	FAO, 2017
TEMP	Average monthly temperature (°C)	WB-FAO, 2017
RAIN	Average monthly precipitation (mm)	WB-FAO, 2017
CO_2-e	Concentration level of carbon dioxide equivalent emitted through rice cultivation, in gigagram	FAO, 2017
SEED	Amount of paddy rice seedlings, in tons	FAO, 2017

climate change in the WAEMU countries, the World Bank (2010) methodology was applied (Ignaciuk and Mason-D'Croz, 2014). Following this methodology, the R&D spending by 2050 were projected based on Equation 3:

$$RD_n = \left[\left(\frac{g_i g_c}{10000} + 1\right) RD_{n-1}\right] \tag{3}$$

where RD_n is the annual expenditures on agriculture R&D, g_i represents the historical growth rate of agricultural R&D per country, g_c is the historical growth multiplier in Table 1.

Availability of data and Materials

The dataset supporting the conclusions of this article is included within the article and its additional files. The study was based on annual panel data of 37 observations (1980-2016) obtained from different sources, including the Food and Agriculture Organization of the United Nations (FAO) and the World Bank (WB). Table 2 provided variable definitions and data sources related to the crop yields model.

RESULTS AND DISCUSSION

Unit-root test, descriptive statistics analysis, and climate change impacts analysis

Unit-root test on variables

Table 3 showed that all the underlying variables expressed in logarithm were stationary at the level according to Levin et al. (2002) t values method.

Descriptive statistics analysis: Variability among countries

Table 4 provided the countries specificities concerning the average paddy rice yields, as well as the climatic variability and the amount of seedlings. For the overall, the variability of paddy rice yields appeared to be significant in reference to the values of maximum and minimum, on the one hand, and to the value of standard deviation in relation to the mean value, on the other hand. For each country, the statistics also showed a significant discrepancy between the values of standard deviation and their corresponding mean values. However, this discrepancy varied from one country to another, indicating that the magnitude of paddy rice productivity did differ according to factors specific to each country, such as climatic conditions and technologies used (Kabir, 2015). On the basis of their respective mean values compared to the overall mean value, Niger, Senegal and Mali were ranked the top three countries with high yielding of paddy rice over the period of study.

It may be established that the seven countries did have the same characteristic feature regarding the prevailing temperature. On the one hand, according to the specific mean values (between 26.6° and 28.8°) compared to the overall mean value (27.9°). On the other hand, according to only the overall value of standard deviation which was practically negligible? Here, the relationship between paddy rice yields and temperature still remained undetermined. The econometric estimation might further throw more light on this unclear liaison.

Concerning the specific mean rainfall levels, Cote-d'Ivoire, Togo, Benin and Burkina-Faso appeared to be the luckiest beneficiaries from the goodness of the nature in terms of rainfall comparatively to the overall value of this variable. The countries of Niger, Mali, and Senegal, seen above as the top in yielding, have meanwhile recorded the lowest mean values of rainfall. This outcome was apparently close to that of Kabir and Golder (2017) by stressing a negative relationship between paddy rice yields and the levels of rainfall.

The statistics also showed that Mali, Burkina-Faso, and

Table 3. Unit-root test* on variables (Levin, Lin & Chu t* method).

Variable in logarithm	Unit-root test in	Test statistic	P-value	Integration order
LYIELD	Individual effects, individual linear trends	-6.52336	0.0000	I(0)
LTEMPER	Individual effects, individual linear trends	-9.90278	0.0000	I(0)
LRAIN	Individual effects, individual linear trends	-11.9716	0.0000	I(0)
LCO2	Individual effects, individual linear trends	-3.60020	0.0002	I(0)
LSEED	Individual effects, individual linear trends	-2.56325	0.0052	I(0)

*From Eviews software. Null hypothesis: Unit root (common unit root process).

Cote-d'Ivoire have been the grand emitters of greenhouse gas (CO_2-e) coming from rice cultivation, whereas Togo and Benin appeared to be the small emitters. There was difficulty to establish a clear nexus between paddy rice yields and GHG emissions. For example, Mali has yielded a large amount of rice with a high level of GHG emissions, whereas Cote-d'Ivoire has yielded a small quantity of rice with also a high level of GHG emissions. However, the analysis was grounded on Burkina-Faso and Cote-d'Ivoire; it may be realized that paddy rice yields and GHG emissions were negatively linked (OECD, 2013).

In addition, it is shown that Cote-d'Ivoire and Mali have consumed the largest amount of seedlings over the period, in reference to the overall value, whereas Benin and Niger have consumed the smallest quantities. This indicated that the scales of investment made in order to extend the agricultural productivity did differ, to a certain extent, from one country to another (Schoneveld, 2014). A remark was the difficulty to establish a clear nexus between paddy rice yields and the amount of seed consumed, meaning that the variability of paddy rice yields did depend on other unrevealed factors or specificities. Indeed, the case of Mali allows pondering on a positive liaison, whereas that of Cote-d'Ivoire did reveal a negative relation.

Estimation of climate change impacts on paddy rice productivity

At first, the Hausman test showed that Random-Effects model (no heterogeneity between countries) was not appropriate. Moreover, the null hypothesis that all the dummy variables are jointly equal to zero could not be accepted (Wald test). Therefore, the suitability of Least Square Dummy Variables (LSDV) model or fixed effects model was admitted in the study.

Based on Equation (2), the impacts of climate change on the growth of paddy rice yields were estimated (Table 5). The extent of the impacts varied obviously across the countries. Although climate change was expected to have a negative impact on yields in the majority of cases, in a few cases however, a boost in yields may be expected. Globally, the regression model performed well, predicting 67% of the specified equation correctly. The results showed that the growth of paddy rice yields was affected significantly by all the underlying variables except for *LRAIN*. In total, a negative sign tended to prevail over the aggregate sum of coefficients relating to the climate variables, highlighting a negative impact of climate change on paddy rice yields in the WAEMU area. This outcome did match up with the work of Egbendewe et al. (2017).

The technological progress (*TREND*) appeared to foster significantly the growth of rice productivity. Henceforth, adopting new innovations through machinery, biotechnology, chemical technology, and new management became a tremendous beneficial action in increasing agricultural growth (Alston, 2010) or rising farm revenue (Berihun et al., 2014). However, with regard to food security goal, policies and actions are needed so as to make the technologies available and affordable to smallholders (Ignaciuk, 2015; Powlson et al., 2011).

The climate variable relating to temperature would impact negatively the growth of paddy rice yields to a great extent. This indicates that global warming would be a serious hindrance to the growth of rice productivity in the WAEMU area over the years. Consistently, IPCC[1] (2014), Nelson et al. (2014) and Rosenzweig and Parry (1994) do alert that large decreases in agricultural productivity are even expected to occur in the developing countries by 2050, depending on the harshness of the climatic shocks. However, their statement was made on the basis of assumption that no action was carried out to define appropriate strategies for adaptation and to reduce the GHG emissions. On the other side, the outcome contradicted the study of Sommer et al. (2013) indicating that the increase in temperature in response to climate change was the most important factor that led to earlier and faster crop growth in Central Asia.

The climate variable pertaining to rainfall would have a positive impact on the growth of paddy rice yields in the WAEMU area. In other words, when the quantity of water is sufficient, it fosters paddy rice productivity. The result here was similar to that obtained by Sommer et al. (2013). However, the variable appeared insignificant in this study, perhaps due to the richness in hydrologic endowments that the nature has bestowed upon the

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[1] IPCC = Intergovernmental Panel on Climate Change

Table 4. Variability of paddy rice yields and climate variables among countries (WAEMU) (Sample: 1980-2016; total panel observations = 259).

Country	Statistic	Yield (kg/ha)	Temperature (°C)	Rain (mm)	CO_2-e (gigagram)	Seed (tons)
Benin	Mean	20427,595	27,88295	85,723973	14,74	1074
	Std Dev.	8096,3066	0,317049	9,2348112	13,15115	944,22
	Maximum	39362	28,578	103,12	43,86	2983
	Minimum	7172	27,257	63,513	3,10	211
Burkina-Faso	Mean	19833,162	28,61465	64,02373	302,55	3036,3
	Std Dev.	3968,2327	0,333364	6,6215565	226,3833	2268
	Maximum	27095	29,211	81,111	754,95	7213
	Minimum	10991	27,955	50,307	94,20	900
Cote-d'Ivoire	Mean	16294,541	26,57443	110,65757	275,21	52860
	Std Dev.	5228,348	0,277211	11,542133	63,06132	17694
	Maximum	30546	27,157	144,828	416,60	93014
	Minimum	9474	25,922	80,23	217,87	37393
Mali	Mean	20620,73	28,80357	25,446054	540,32	38240
	Std Dev.	9035,7695	0,400553	3,4014607	271,2487	18737
	Maximum	48868	29,748	33,175	1220,70	83041
	Minimum	6620	28,034	18,888	169,92	11559
Niger	Mean	28912,297	27,71227	13,787405	40,20	1252,4
	Std Dev.	10509,034	0,432227	2,7345517	11,95494	328,91
	Maximum	61714	28,714	18,973	61,74	1800
	Minimum	10189	26,795	6,496	10,91	318
Senegal	Mean	26125,27	28,49889	57,491243	130,23	6329,7
	Std Dev.	8301,9143	0,373836	8,9092896	37,36922	1838,5
	Maximum	42745	29,204	76,777	216,40	10305
	Minimum	9625	27,688	38,135	66,75	3178
Togo	Mean	16989,622	27,38468	94,234541	9,07	3226,1
	Std Dev.	6506,6891	0,312455	10,639088	5,281011	1870,4
	Maximum	28233	28,151	112,983	22,63	7698
	Minimum	4624	26,689	73,204	3,21	1092
Overall	Mean	21314.75	27.92449	64.48064	187.4749	15145.45
	Std Dev.	8710.662	0.811276	34.02496	226.9292	21990.57
	Maximum	61714.00	29.74800	144.8280	1220.700	93014.00
	Minimum	4624.000	25.92200	6.496000	3.104100	211.0000
	Observations	259	259	259	259	259

majority of the countries. Looking it in a specific way, the variable might be significant for some countries and insignificant for others.

The increase in the concentration level of GHG (CO_2-e) emitted would influence negatively the growth of paddy rice yields in the WAEMU area, but this harmful impact appeared less insistent than that provided by the rising of temperature (OECD, 2013).

The amount of seedlings applied to soil was destined to capture the impact of extensive agriculture. It was found that as the number of tons of seedlings increased, so did the growth of paddy rice yields in the WAEMU area. The outcome showed that the positive benefits drawn from a large scale seedling production might offset the negative externalities generated by GHG emissions (Schoneveld, 2014).

Moreover, the results indicated that all the country dummies were positively significant, emphasizing the existence of specificities inherent to each country that need to be taken into account while analyzing the impact of climatic conditions on rice productivity (Tazhibayeva and Townsend, 2012). These specificities could be,

Table 5. Response of the growth of paddy rice yields to climate variables in the WAEMU area (Sample: 1980-2016: total panel observations = 259).

Variable	Coefficient	
	LSDV model	Pooled OLS model
Constant	13.85295 (4.707681)***	16.84049 (4.855172) ***
TREND	0.022402 (0.002390) ***	0.022402 (0.002390) ***
LTEMP	-3.587946 (1.458181) **	-3.587946 (1.458181) **
LRAIN	0.126928 (0.119866)	0.126928 (0.119866)
LCO_2-e	-0.123798 (0.061109) **	-0.123798 (0.061109) **
LSEED	0.248892 (0.064687) ***	0.248892 (0.064687) ***
Dum1	5.586607 (0.518726) ***	
Dum2	5.015949 (0.511815) ***	
Dum3	2.882779 (0.429405) ***	
Dum4	2.891949 (0.373166) ***	
Dum5	2.885850 (0.269598) ***	
Dum6	1.649666 (0.196980) ***	
Adjusted R^2	0.673	0.673
F-statistic	49.206***	49.206***
DW stat	0.954	0.954

The Std. error in parenthesis (…); ***, **, * indicates significance at the 1, 5 and 10% levels, respectively. Dum7 is omitted so as to avoid dummy variable trap.

Table 6. Types and examples of adaptation options at different levels of agriculture.

Adaptation	Example	Implementation
Technological development	Crop development	Public and private investment in new crop varieties and hybrids to increase tolerance to water and heat stress or other relevant adverse conditions
	Weather and climate information systems	Public and private investments in monthly and seasonal forecasting and early warning systems
	Resource management innovations	Public and private investment in water management innovations to address moisture deficiencies and risk of drought and changing seasonality of precipitation
Technological adoption	Farm production innovations	Diversification of crop types and varieties including crop substitution. Diversifying livestock types and breeds and changing seasonality of feedlot practices
	Irrigation	Implement on-farm irrigation practices to avoid recurrent drought risk
	Timing of operations	Changing timing of operations to address changing duration of growing seasons and associated changes in temperature and moisture

Source: Adapted from Smith and Skinner (2002).

among others, effective irrigation system, sustainable farming practices (e.g. multi-cropping, crop rotation and agroforestry), or relevant management system (e.g. integrated nutrients management and integrated pests management).

Adaptation to climate change impacts

Identifying a set of adaptation options

Table 6 provided a picture of measures that may affect adaptation to climate change.

Estimation of R&D costs

Building an agricultural R&D system (e.g. developing new technologies that increase yields) was proved to bring an undeniable boon to countries for mitigating climate change negative impacts (Fuglie and Wang, 2012). Assuming that there was an easy access to high-quality seeds on a market of perfect competition, FAO (2015)

Table 7. Estimates of public spending in R&D for the WAEMU countries (2017-2050).

Parameter	Period/year	Benin	Burkina-Faso	Cote-d'Ivoire	Mali	Niger	Senegal	Togo
Historical growth rate g_i (%)	1981-2016	3.170	1,856	-1,007	-0,807	0,767	-0,155	-3,590
R&D spending (million constant 2011 local currency)	2016	4965,447	10353,246	18732,865	7956,422	3215,959	12121,437	1483,945
Average projections of R&D spending (million constant 2011 local currency)	2017-2020	4978,038	10368,619	18717,781	7951,285	3217,932	12119,930	1479,682
	2021-2030	5027,133	10428,408	18659,447	7931,413	3225,589	12114,092	1463,281
	2031-2040	5138,169	10562,739	18530,263	7887,360	3242,698	12101,109	1427,432
	2041-2050	5235,071	10678,983	18420,517	7849,888	3257,4	12090,018	1397,48

recommended that the use of improved varieties of seeds shall continue so as to enhance crop productivity gains in the future. Evidence (Oleson and Porter, 2009) also revealed that rotating species may foster soil erosion control, nutrient loss reduction and genetic diversity. Following the same approach as Wreford et al. (2010), the orders of magnitude for the potential expenditures in R&D that would be needed globally to develop new crop varieties (rice variety included) was calculated as shown in Table 7. Thus ceteris paribus, Benin, Burkina-faso and Niger were recommended to increase constantly their annual R&D spending by approximately 3.2, 1.9 and 0.8% respectively throughout the period (2017-2050). Cote-d'Ivoire, Mali, Senegal and Togo, meanwhile, were advised to maintain or, if desired, increase their R&D planning.

Conclusion

This study aimed mainly to understand the nexus between climate variables and paddy rice productivity in seven countries members of the West African Economic and Monetary Union (WAEMU), and then, proposed a mitigation measure that may be undertaken. The analysis first explored the potential impacts of climate variables on rice yields by using panel data covering the period 1980 to 2016. It then went on to calculate the investments needed in R&D for developing new crop varieties (World Bank, 2010).

The results showed that the growth of paddy rice productivity was positively affected by the level of technological progress, the rainfall or quantity of water, and the amount of seedlings. In contrast, the concentration level of temperature (global warming) and the mass of carbon dioxide appeared to be negatively related to the growth of rice yields. Obviously, the extent of the impacts varied according to the specificities (heterogeneity) among the countries, which was admitted through the positive significance of country dummy variables. However, the findings retained that the aggregate impact of climate variables on paddy rice productivity was negative. In this respect, some countries namely, Benin, Burkina-faso and Niger were strongly recommended to increase constantly their annual R&D spending throughout the period 2017 to 2050 so as to face the consequences of the global warming and then, withstand food insecurity. This suggestion was very close to that of Schoneveld (2014) in terms of policies and strategies seeking to minimize damages due to climate change in both developed and developing areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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