Effect of climate change on cereal yield: evidence from Benin and Burkina Faso

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Abstract

Agricultural sector is most threatened by climate than the others sectors. Given that many rural people livelihoods is coming from agriculture in Africa, the vulnerability of the sector to climate change is likely to maintain them under extreme poverty and food insecurity. The paper aims to analyze the effects of climate change on cereal yield in Benin and Burkina Faso. Specifically, it determines the effect of weather variables such as precipitations and temperature and greenhouse emission gas (CO2) on cereals yields and then makes a comparison of these effects between the two countries.

Using a time series data from 1975 to 2011 the results of the study indicate that cereal yield is more influenced by precipitations in Burkina Faso and by temperature in Benin. The cereal yield seems to be not affected by temperature in Burkina Faso and by precipitations in Benin. Moreover, the regression model including the CO2 concentration shows a non-significant effect of the CO2 emission on the cereal yield in the two countries.

Keywords: Climate change, Cereal yield, Production function approach

J.E.L. Classification: E23 - O13 - Q54

Résumé

Le secteur agricole constitue le secteur le plus menacé par les effets du changement climatique. Cette vulnérabilité a pour conséquence l'aggravation de la pauvreté et de l'insécurité alimentaire en milieu rural africain parce que beaucoup de gens dépendent de l'agriculture pour leurs survies. Le but de ce papier est d'analysé les effets du changement climatique sur la production céréalière au Benin et au Burkina Faso. Spécifiquement le papier détermine l'influence des variables climatiques tels que les précipitations, la température et l'émission de CO2 sur le rendement céréalier en faisant une comparaison entre les deux pays.

Les données en série temporelles de 1975 à 2011 ont été utilisées pour les régressions. Les résultats indiquent que le rendement céréalier est sensible aux variations des précipitations au Burkina Faso et à la température au Bénin. Cependant il ne semble pas être influencé par la température au Burkina Faso et les précipitations au Benin. En plus le modèle de régression avec l'émission de CO2 montre un impact non-significatif sur le rendement céréalier au Bénin et au Burkina Faso.

Mots Clés : Changement climatique, Rendement céréalier, Approche de fonction de production

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1- Introduction

Agriculture is the major sector of sustainable development in Africa given its contribution to the economic growth and employment. It employs over 70 % of the labor force in Africa (Wisdom et *al*, 2011) and contributes significantly to GDP. Indeed in Benin and Burkina Faso, the agricultural sector contributes respectively about 36 % and 35 % to the GDP and employs 70 % and 92 % of the labor force (FAO, 2013). However the level of agricultural productivity is low especially for staple food crops in Benin and Burkina Faso. The average yield of cereals has been 1230 and 1478 kg per hectare in Burkina Faso and Benin respectively from 2009 to 2013 while the average for developing countries is 2.5 tons per hectare and 3.7 tons per hectare for the world (World Bank, 2013). This low level of productivity remains the main challenge for any poverty reduction strategy in Africa and mainly in both countries.

About 95 % of the cultivated area in both Benin and Burkina Faso are under rainfed. This demonstrates the vulnerability of agriculture to climate change. Climate change is expected to hit developing countries the hardest. Higher temperature, change in precipitation patterns, rising sea levels, and more frequent weather-related disasters pose risks for agriculture, food, and water supplies.

Benin is vulnerable to three major climate risks such as drought, late and heavy rains and flooding. In 2011 heavy rains have resulted in severe flooding of municipalities and communities of Lokossa, Athiémé Bopa and Cotonou affecting about 500 households within the inaccessible areas. There has been extensive damage to poultry and livestock, and many hectares of farmland and crops have been destroyed (IFRC, 2011). One year later the Niger River burst its banks in September 2012 on a distance of at least one kilometer destroying almost everything in its path and causing massive damage. North Benin's municipalities of Karimama and Malanville were most affected. Approximately 3,000 houses were destroyed, forcing more than 10,000 people to move and find shelter with host families and in schools. More than 43,000 people were affected by the disaster (IFRC, 2013). Heavy rains during the third quarter of 2013 led to the Niger River overflowing its banks, which caused flooding in the Malanville and Karimama municipalities in northern Benin. The flash flood affected 13,000 hectares of farmland, leaving more than 10,000 people displaced and more than 30,000 affected. By the end of November, the flood waters had receded and some of the displaced had started returning to their damaged houses, but many households remained in temporary camp sites in Malanville and Karimama municipalities where humanitarian actors including the Red Cross provided basic immediate support (IFRC, 2013).

In Burkina Faso the climate variability and change are also characterized by recurrent droughts, inadequate or poorly distributed rainfall in time and space, lower or total drying groundwater supply sources, heavy rains and flooding. Between June and September 2012, heavy rains affected most of Burkina Faso, flooding many villages in the central and north eastern regions, including the four provinces of the Sahel region. The floods affected a total of 47,671 people with 33 wounded and 18 people killed (IFRC, 2012). In August 2013 severe floods were also reported in many countries across the Sahel. In Burkina Faso, four regions were affected: Est, Boucle de Mouhoun, Sahel and Hauts-Bassins. At least 751 households and 6,712 people were affected (OCHA, 2013).

These floodings cause several consequences such as declining of soil fertility, accelerated erosion, loss of vegetation, reduction of revenue, and the loss of wildlife and genetic depletion of animal and plant species (Benoît, 2008)**.** In total, the most vulnerable resources are subsistence agriculture, land, biodiversity and water resources. The most vulnerable social groups are small farmers and fishermen.

In such climatic context a better quantification and understanding of climate impacts on crop yield is needed for the purpose of averting its effects to the total crop production (Roudier *et al*, 2011). For instance the agricultural production including access to food in many African countries is projected to be severely compromised. By 2020, yields from rain-fed agriculture could be reduced by up to 50 % (Boko *et al.* 2007). This would further adversely affect food security and exacerbate malnutrition.

An effective agricultural policy must take into account the effects of climate change in order to meet the commitments of Maputo in 2003 to make agriculture the engine of agricultural growth in Africa. The present study makes contribution in that direction. It provides clear answers to the following concerns: what are the effects of climate change on cereal productivity? Are there any difference in the climate change effects between Benin and Burkina Faso?

The paper aims to analyze the effects of climate change on crop yields in Benin and Burkina Faso. Specifically, it determines the effect of weather variables such as precipitations and temperature and the effect of the greenhouse emission (CO2) on crop yields and then makes a comparison of these effects between Benin and Burkina Faso.

To achieve our objectives, the remaining of the paper is structured as follows. In the subsequent section we discuss the literature on the climate change effect. Section 3 outlines the methodology of the study. Empirical results are presented in Section 4. The final section concludes and gives the policy recommendation.

2- Effect of climate change on agriculture: a review of evidence

Climate change is a major threat to sustainable development. Agricultural sector is most threatened by climate than the others sectors. The Agricultural vulnerability to climate change puts many rural people under extreme poverty and food insecurity situation. Therefore understanding of the climate cause and effect in order to develop an adaptation and mitigation policy becomes important to achieve sustainable agricultural production and eradicate hunger.

2-1- Drivers of climate change

The causes of climate change can be divided into two categories: those that are due to natural causes and those that are created by human activities. The more prominent natural factors responsible for climate change are continental drift, volcanoes, ocean currents, the earth's tilt, and comets and meteorites. As an example, although the volcanic activity may last only a few days, yet the large volumes of gases and ash can influence climatic patterns for years. Millions of tons of sulphur dioxide gas can reach the stratosphere from a major eruption. The gases and dust particles partially block the incoming rays of the sun, leading to cooling.

Every day human through theirs activities contribute to the change in climate. While the population is growing the land area available for agriculture is limited. To feed the foods need of the growing population high-yielding varieties of crop are being grown to increase the agricultural output from a given area of land. However such high-yielding varieties of crops require large quantities of fertilizers and more fertilizer. This means more emissions of nitrous oxide both from the field into which it is put and the fertilizer industry that makes it. Pollution also results from the run-off of fertilizer into water bodies. Timber is used in large quantities for construction of houses, as source energy, for paper, etc. So large areas of forest have to be cut down which bring the deforestation challenges. The transportation means such cars, buses and trucks are run mainly on petrol or diesel, both fossil fuels and are contributing to greenhouse gases emissions. Also large quantities of waste are generated in the form of plastics which remain in the environment for many years and cause damage.

Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. The rate and magnitude of global climate change is determined by radiative forcing, climate feedbacks and the storage of energy by the climate system. According to the IPCC (2013), the global radiative forcing (RF) from emissions of well-mixed greenhouse gases (CO2, CH4, N2O, and Halocarbons) for 2011 relative to 1750 is 3.00 watts per square meter (Wm^{-2}). Emissions of CO2 alone have caused an RF of 1.68 (from 1.33 in 1750 to 2.03 in 2011) Wm^{-2}. Including emissions of other carbon-containing gases, which also contributed to the increase in CO2 concentrations, the RF of CO2 is 1.82 (from 1.46 in 1750 to 2.18 in 2011)Wm^{-2}. The emissions of CH4 alone have caused an RF of 0.97 Wm^{-2} for 2011 relative to 1750. This is much larger than the concentration-based estimate of 0. 48 Wm^{-2}. This difference in estimates is caused by concentration changes in ozone and stratospheric water vapor due to CH4 emissions and other emissions indirectly affecting CH4. Emissions of stratospheric ozone-depleting halocarbons have caused a net positive RF of 0.18 (from 0.01 in 1750 to 0.35 in 2011)Wm^{-2}. Their own positive RF has outweighed the negative RF from the ozone depletion that they have induced. And then emissions of short-lived gases contribute to the total anthropogenic RF. Emissions of carbon monoxide (CO) are virtually certain to have induced a positive RF, while emissions of nitrogen oxides (NOx) are likely to have induced a net negative RF.

Greenhouse gases contributed to the global mean surface warming likely to be in the range of 0.5°C to 1.3°C from the period 1951 to 2010, with the contributions from other anthropogenic forcing, including the cooling effect of aerosols, likely to be in the range of − 0.6°C to 0.1°C. The mains sources of greenhouse gases emissions come from energy, industry, transport, waste and agriculture. For instance, over the period 2000 to 2009 in European countries, in the agricultural sector the majority of emissions comes from agricultural soils (nearly 51 % in 2009), followed by emissions from enteric fermentation in animals (over 31 %) and over 17 % from manure management (Eurostat, 2011). Agricultural soils emit methane and nitrous oxide through soil denitrification. Amongst the factors that influence emissions from agricultural soils is the amount of fertilizers, the type of application techniques, the fertilizer type used, the incorporation time.

2-2- Empirical effect of climate change on agriculture

Although the impact of climate change on agriculture has become a topic of interest only in the 1990s, a large body of literature has been developed to analyze these effects, both in developed and in developing countries. Economists have spent almost two decades quantifying the impacts of climate change on agriculture. A consensus has emerged that developing countries are more vulnerable to climate change than developed countries, because of the predominance of agriculture in their economies, the scarcity of capital for adaptation measures, their warmer baseline climates and their heightened exposure to extreme events (Parry *et al.* 2001; IPCC, 2007).

The World Bank (2007) identifies five main factors through which climate change affects the productivity of agricultural crops: changes in precipitation, temperature, carbon dioxide (CO2), fertilization, climate variability, and surface water runoff. Increased climate variability and droughts will affect livestock production as well. Crop production is directly influenced by precipitation and temperature. Precipitation determines the availability of freshwater and the level of soil moisture, which are critical inputs for crop growth. Based on an econometric analysis, Reilly *et al*. (2003) found that higher precipitation leads to a reduction in yield variability. Therefore, higher precipitation will reduce the yield gap between rainfed and irrigated agriculture, but it may also have a negative impact if extreme precipitation causes flooding (Falloon and Betts 2009).

Sonneveld, *et al*. (2012) found that under average climate change conditions in the Ouémé River Basin in Benin, the current low yields are not reduced, provided that cropping patterns are adjusted, while price increases partly compensate for the remaining adverse effects on farmer income. Consequently without any policy intervention, farm incomes remain relatively stable, though at low levels and with increased occurrence of crop failures after extreme droughts. Their scenario simulations show that there are also beneficial aspects that can with adequate interventions even turn losses into gains.

Ayinde *et al*. (2010) used descriptive statistics and granger causality test analysis as the analytical tools to determine the relation between agricultural production and climate change in Nigeria. The Granger causality approach revealed that changes in rainfall positively affects agricultural production in Nigeria. Therefore they recommended that if agricultural production will be increased and sustained, irrigation is the most suitable mode of water provisions, which would have not have negative influence on the environment.

Reviewing the study on the impact of climate change on crop production in Nigeria, Maikasuwa and Ango (2013) observed that the two most important parameters impacting heavily on crop production were the rainfall and greenhouse emissions (CH_4 and CO_2) and the effect of the latter was more severe.

Kurukulasiriya and Rosenthal (2003) noted that food productivity in Kenya may well increase with higher levels of atmospheric CO_2 and climate change induced increases in temperatures accompanied by some increases in precipitation. These arguments were also supported by Schultz *et al.* (2011) who argue that maize production in Zimbabwe is expected to fall as a result of increased temperatures that shorten the crop growth period. In the Limpopo region of South Africa the impact of precipitation on maize yield is weaker than that of temperature (Akpalu *et al*. 2011).

Using the production function approach Turpie *et al*. (2002) analyze the economic impact of climate change in South Africa. Their study addresses impacts on natural, agricultural, man-made and human capital. They predict that the impact of climate change on rangelands will be positive, with the fertilization impact of CO_2 outweighing the negative effects of reduced precipitation. However they find out that the impact of climate change on maize production will be negative both 'with' and 'without' CO_2 fertilization. Blanc (2012) used the same approach to analyze the impact of climate in Sub Saharan Africa. She related yields to standard weather variables, such as temperature and precipitation, and sophisticated weather measures, such as evapotranspiration and the standardized precipitation index. Blanc (2012) shows that temperature and precipitation are important determinant of the crop yields in Sub Saharan Africa.

The Ricardian model was also used to analyze the effect of climate change (Mendelsohn and Shaw, 1994; Mendelsohn et *al*. 2000; Seo *et al*. 2005). Mendelsohn and Shaw (1994) used the Ricardian technique to estimate the value of climate change in United State of America agriculture, using cross-sectional data for about 3000 Counties. Their results showed that climate has complicated effects on agriculture, which can be highly non-linear and vary by season. Specifically they found that increased temperatures are likely to reduce average farm values, but increased precipitations do improve farm values. Their findings further shows that a scenario of increasing temperatures by an average of 5°C and corresponding average precipitation of 8% leads to a loss in land value from warming to an annual neighborhood damage of 4 to 5%. However the same policy change scenario results in a 1% gain when using the crop revenue approach. Kurukulasuriya and Mendelsohn (2008) conducted the same study in Africa. Relying on farm data from an eleven countries survey of over 9500 farmers, they have regressed annual net revenue on climate and other variables. By doing that Kurukulasuriya and Mendelsohn (2008) confirmed that current climate affects the net revenues of farms across Africa.

Seo *et al.* (2005) also employed the Ricardian approach to measure the impact of climate change on Sri Lankan agriculture, focusing on four major crops. The authors found that global warming is expected to be harmful to Sri Lanka but increases in rainfall will be beneficial. They also find that with warming, the already dry regions are expected to lose large proportions of their current agriculture, but the cooler regions are predicted to remain the same or increase their output. They concluded that climate change damages could be extensive in tropical developing countries but will depend on actual climate scenarios.

Molua (2002) in an analysis of the impact of climate on agriculture in Cameroon found that increased precipitation is beneficial for crop production and that farm level adaptations are associated with increased farm returns. Similar results were find by Ouédraogo (2012) using the Ricardien model in Burkina Faso. He found that the increase of 1 % of rainfall leads to 14.7 % increase of agricultural income. The simulation results indicate that farmers will loss all their agricultural income if the rainfall decreases to 14 %. In China, Chen et *al.* (2014) argue that increase of average temperature improved single cropping rice production on national level by up to 11 % relative to the average over the study period however it resulted in an overall loss of double cropping rice by up to 1.9 %.
The studies that were employed the Ricardian approach have supported findings by Mendelsohn and Shaw (1994) of an adverse impact of climate change on agriculture.

3- Materials and Methods

3-1- Model specification

In order to determine the effect of climate change on cereal productivity in Benin and Burkina, we specify a production function approach (Ouri, 1965; Turpie et al, 2002; Kurukulasiriya and Rosenthal, 2003; Blanc, 2012). To avoid multicollinearity two alternative specifications are considered in the study (Blanc, 2012).
A first model includes the most commonly used weather indicators, which are precipitation and temperature averages. The production model can be specifying as follows:

$$Y = f(X, T, T^2, P, P^2, T * P, T^2 * P, T * P^2) \quad (1)$$

Where Y represents cereal yield, X is the set of relevant annual input which includes area harvested and fertilizer consumption. T and P are respectively temperature and precipitation which are the most used weather indicators. Because of the non-linear weather effect on crop yields a quadratic form for weather variable are included in the model. Also interaction terms between weather variables are used to determine the potential effect of one weather variable given the effect of the other weather variable.

A second model considers the effect of CO2 concentration. Indeed CO2 concentration is highly correlated with weather variables as changes in CO2 concentration drive changes in climate. Therefore traditional weather variables (temperature and precipitation) are not included in the specification. The CO2 model is specified as:

$$Y = f(X, CO2) \qquad (2)$$

All the explanatory variables included in the models are as follows:

Table 1: Explanatory variables and expected signs

Variables	Descriptions	Expected signs
T	Temperature	-
P	Precipitation	+
A	Area harvested	+
CO2	CO2 concentration	-

Source: Authors

3-2- Technical analysis

The study area is Benin and Burkina Faso. These countries were chosen because of their difference in climate condition. Benin is a country with climate changes from savannah-desert in the North to tropical rainforest in the South while Burkina Faso is a Sahel country. Temperatures are generally hot in Burkina Faso. The data used in the study are secondary data from 1975 to 2011. Cereal yield, area harvested and CO2 concentration variables were collected from the World Bank database. The weather variables for Benin are from the Benin Meteorological Agency and those of Burkina Faso are from the Royal Netherlands Institute web site.

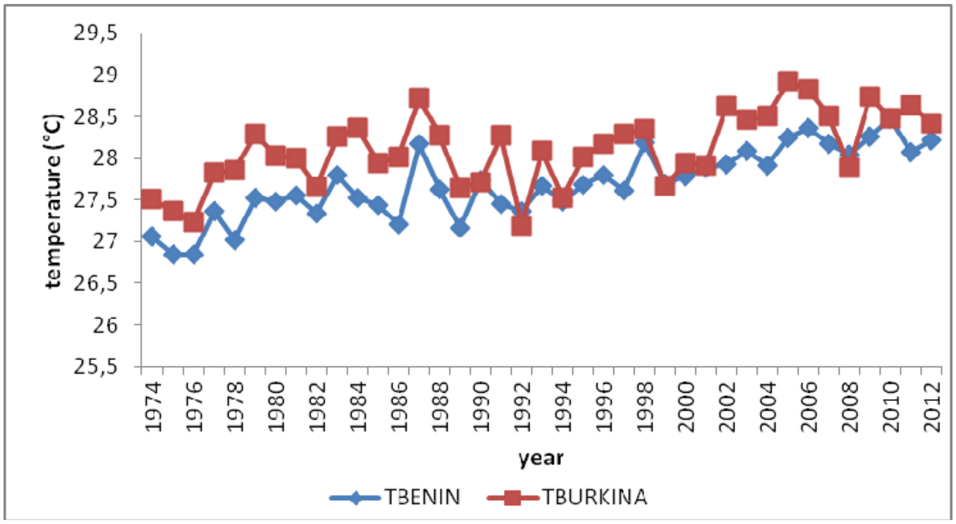
We estimate the multiple regression models for each country using the ordinary least square (OLS). All the data excluded the weather and greenhouse gas emission variables are log-transformed to improve the distribution of variables. So the model estimates elasticity. Weather variables are not log-transformed to produce semi-elasticity. This allows direct determination of the impact on crop yield. So the interpretation could be as a 1°C increase in temperature or a 10 mm increase in rainfall has x % change in crop yield. Also in contrast to several studies which used an average weather variable (Ouédraogo, 2012; Oluyole et *al*, 2013; Nwaiwu, *et* *al*.2014) we used the variation of weather variable from year to year. In fact we assume that climate change or climate variability must be better captured by the average change of the weather variable.

4- Results and Discussions

4-1- Trends of climate change

The evolution of the temperature seems to be the same in Benin and Burkina Faso even if in an absolute value, the degree of temperature is higher in Burkina Faso than Benin (Figure 1). It was only in 1992 that the average temperature in Benin is higher than that in Burkina Faso.

Figure 1: Evolution of temperature in Benin and Burkina Faso

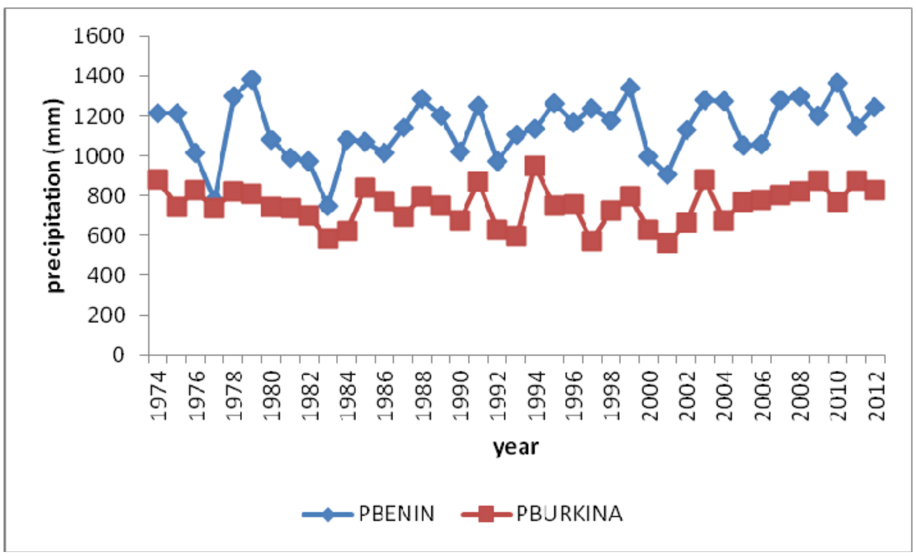


Source: Authors

Indeed the two countries are different in term of climate. While Benin is a country with relative good climatic condition, in Burkina Faso the climate is worse. Between 1974 and 1991, the average temperature in Burkina Faso was 27.9 °C against an average of 28.3 °C from 1993 to 2012. In the same time the average temperature in Benin was 27.3 °C against 27.9 °C. Although Burkina Faso continues to experience high temperature we observe that there is more increasing in average temperature in Benin than Burkina Faso since 1993.

The trends of precipitation over a period of the study show that Benin witnessed more rainfall than Burkina Faso (Figure 2). Indeed the average precipitation of the rainfall in Benin between 1974 and 2012 was 1138.42 mm against 752.84 mm in Burkina Faso. We can conclude from the figures 1 & 2 that the climate is more favorable in Benin than the case of Burkina

Figure 2: Evolution of precipitation in Benin and Burkina Faso



Source: Authors

4-2- Econometric analysis

Augmented Dickey- Fuller test is used to test for the presence of the unit root. The null hypothesis of the presence of a unit root is rejected for the variables included in the models when we did the stationarity test in level. So the variables are integrated in order I (0). This is certainly due to the fact that we used the variation of the variables between times t and t_{-1} in our models. In that case, a cointegration test becomes unnecessary when all the variables of the model are stationary in level. Therefore we estimated the model using the OLS method and we test for the diagnostic tests such as normality test, specification test, heteroskedasticity test and autocorrelation test. All these tests confirmed the quality of the estimations.

Regression results for the weather model are presented in table 2. Results for the CO2 model are not significant for both Benin and Burkina Faso therefore we do not reported.

Table 2: Regression results: dependent variable ΔlnY

	Benin		**Burkina Faso**	
Explanatory Variables	Coef.	Std. error	Coef.	Std error
ΔlnA	-0.3568	0.2268	0.2856*	0.1645
ΔT	-0.1855***	0.0521	0.0133	0.0451
ΔP	0.0002	0.0001	0.0006*	0.0002
ΔT^2	0.1581*	0.0872	-0.0339	0.0816
ΔT^2P	-0.0012*	0.0006	-0.0007	0.0006
$\Delta T P^2$	5.16 e-07	1.43 e-06	4.09 e-06**	1.72 e-06
C	0.0073	0.1890	0.0161	0.0305
Observation	38		38	
R^2	0.34		0.38	
F	0.0077		0.0070	

Source: Estimations results

Although the coefficient of correlation is relatively small for the models estimated for the two countries, it does not mean that the estimators are not consistent. It is simply means that there are others explanatory variables that could explain the dependent variable. A fisher test shows that the models are globally significant and the Ramsey test confirms that the models do not suffer from omissions of variables. The normality test concludes that the residues are normally distributed.

An increase in harvested area has a positive and significant effect on cereal yield in Burkina Faso while in Benin the relation is not significant. For instance, the increasing of area harvested by 10% causes an increasing of cereal yield by 2.8 % in Burkina Faso. The positive and significant effect of harvested area in Burkina Faso indicates that the increasing of cereal yield is due to the extension of area cultivated. This can be explains by the fact that farmers involving in cereal crops are mostly smallholders. Given that more than 50 % of poor live in rural area and combining to the credit market imperfection, they do not have access to productive resources. The only way for them to increase the yield is to increase the farm size. This result confirms several what has been found by several studies on the source of increasing of cereals yields in Burkina Faso (Couty, 1991; Reij and Thiombiano, 2003; MAFAP, 2013)

Temperature has a negative and significant effect on cereal yield in Benin with non-linear responses to change. The effect is non-significant in Burkina Faso. So the increasing of temperature by 1°C causes the decreasing of cereal yield by 0.2 % in Benin. Also the squared temperature and precipitation interaction term is significant. This shows that the threshold effect of temperature on cereal yield depend on the precipitation.

Precipitation has a positive and significant effect on cereal yield in Burkina Faso with non-linear responses to change. The effect is non-significant in Benin. Also the squared precipitation and temperature interaction term is significant. This shows that the threshold effect of precipitation on cereal yield depend on the temperature.

The paper shows that the weather variables such as precipitation and temperature are determinants of the cereal yield in Benin and Burkina Faso. These results are in the same direction with those found by Molua (2002), Seo *et al.* (2005), Ouédraogo (2012), and Blanc (2012).

5- Conclusion

The paper analyzes the impact of climate change on cereal yield in Benin and Burkina Faso. The idea was to analyze how climate change impacts cereal yield in each country and then compare the different effect between the two countries. We used times series data from 1975 to 2011 to estimate two production models. The first model relates the cereal yield to the weather variables such as precipitation and temperature. To avoid multicollinearity the second model was estimated. This includes the CO2 concentration data. However the results of the second model are not significant for both Benin and Burkina Faso. So we based our discussion on the results of the first model. The regression of that model shows that the temperature has a negative impact on cereal production in Benin whereas in Burkina Faso the cereal yield is more affected by the level of rainfall. Thus in these two countries the weather variables that influence the cereal yield is different. These results confirm the fact that in Burkina Faso the rains are relatively scarce and then in Benin the precipitation change is stable over the period of the study while the temperature is more instable in Benin than in Burkina Faso.

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