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Impact of climate change on cotton production in Burkina Faso

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This paper evaluated the impact of climate change on cotton production in Burkina Faso. An econometric analysis resulted in identifying the major factors influencing cotton yields and evaluating the likely effects of future climate change. The results of our study regarding the potential impact of future climate change on cotton yield indicated that further increases in global temperature would significantly reduce the yield of cotton. Future changes in rainfall would also affect cotton production, but compared with the effects of temperature, the effects of rainfall are relatively lesser. Therefore, strategies for reducing the impacts of climate change on cotton production should emphasize the development of heat resistant cultivars rather than drought resistant ones in order to mitigate and adapt them to the effects of climate change.

Key words: Climate change, cotton, economic impact, adaptation, Sahel, Burkina Faso.

INTRODUCTION

Climate change represents one of the greatest environmental, social, and economic threats with which the planet is confronted today. Several climate models suggest that in West Africa, the average temperature is likely to increase while rainfall is likely to decrease. This change will have a significant impact on the livelihoods and living conditions of the population, particularly the poor. According to a report by the Intergovernmental Panel on Climate Change report (IPCC, 2007) developing countries are more vulnerable to climate change than developed countries because agriculture is mainly rainfed and is still the largest sector in their economies.

Despite the urgency of the issue, little research has been carried out regarding these effects in West Africa at the country level. Little is known about the extent of the potential damage in each country. Most studies in sub-Saharan African (SSA) have been conducted at the regional or global level (Rosenzweig and Parry, 1994; Darwin et al., 1995; IFPRI, 2009). However, since agricultural technologies and, environmental and socioeconomic conditions vary from one country to another, climate change is expected to have different effects; therefore, it is important to address the issue of climate change impacts on agricultural productivity at the national level.

This paper focuses on cotton production, a major

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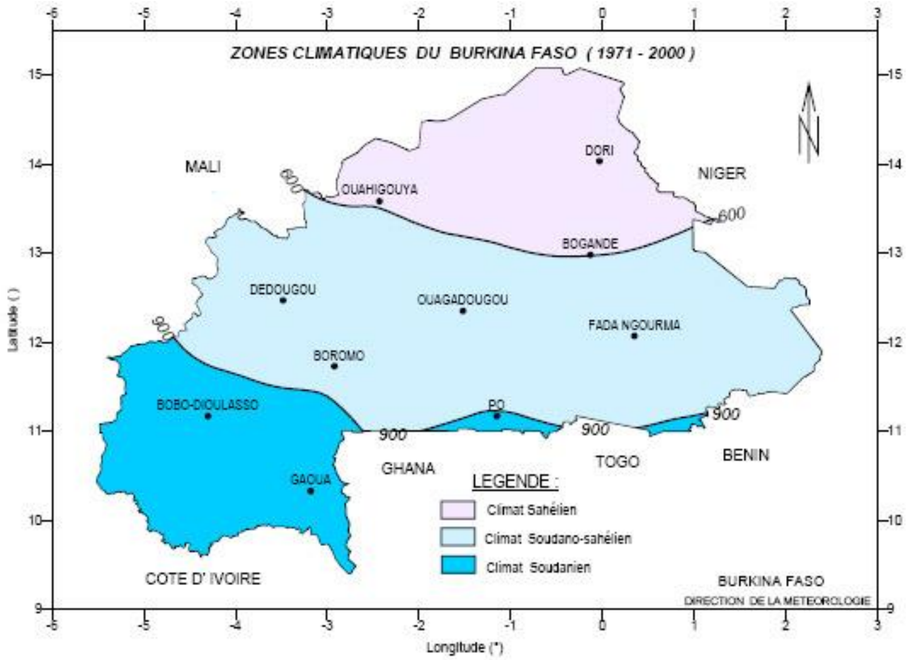

Figure 1. Agro-climatic zones in Burkina Faso.

sector of the economy and agriculture of Burkina Faso. In this country, agriculture represents a large share of the gross domestic product (22%). Cotton is the main export commodity in terms of value, and generates income for approximately 3 million people in the country. Most cotton-farms are family-owned and are small scale (an average of about 1.0 hectare of cotton per farm). Therefore, climate change could be potentially disastrous for the economy of Burkina Faso.

Two major methodologies have been used so far to study the relationship between climate and crop yields: a computer based simulation approach, the so-called crop growth models and a statistical model based on regression analysis. Both methodologies have their advantages and disadvantages (Cai, 2011). Crop growth modeling tools such as Decision Support System for Agrotechnology Transfer (DSSAT), Erosion Product Impact Calculator (EPIC) and Terrestrial Ecosystem Model (TEM) are mathematical representations of phenomena linked to different disciplines such as biology, physics and chemistry (Hoogenboom, 2000; Jones et al., 2003). For instance, EPIC has been used in numerous studies for a variety of purposes and has gained popularity throughout disciplines in agriculture.

However, crop growth modeling is highly complex and requires extensive information such as climate data, soil and management options in order to simulate the crop growing process. Such information is usually incomplete and sometimes unavailable. Because of this disadvantage of crop simulation modeling, regression analysis is an alternative method used for predicting yields in many yield forecasting studies (Schlenker et al., 2009; Yingjie, 2008; Chang, 2002; Lobell et al., 2008; Paeth et al., 2008). Compared to the crop growth modeling approach, data limitations are less of a concern in the regression model (Cai, 2011).

In this study, a non-linear regression model is used to investigate the impact of climate change on cotton yield in Burkina Faso. Coefficient estimates are used to predict the change in yield under alternative climate change scenarios.

MATERIALS AND METHODS

Climate in Burkina Faso

Burkina Faso has a semi-arid tropical climate. The dry season is characterized by the harsh harmattan wind which blows from the north-east to the south-west from October to March. April is the month of humid winds or trade winds bearing monsoons. The rainy season, from May or June to September is characterized by humid winds.

A mass of humid air from the Atlantic proceeds north from the Gulf of Guinea and reaches Burkina from the south-west where the rains start falling in April. At first sporadic, rains gradually cover the whole country from June onwards. August is the wettest month. The rains cease at the end of September. October is when the dry harmattan wind starts blowing throughout the country. The duration of the rainy season decreases progressively from the south-west to the north. The rainfall is very erratic and its volume also decreases from the south-west to the north. There are large seasonal shifts in temperature and their heat rises at night, particularly in the north of the country (Some and Sivakumar, 1994).

The country is divided into three climate zones (Figure 1). These agro-climatic zones also constitute the phyto-geographical regions

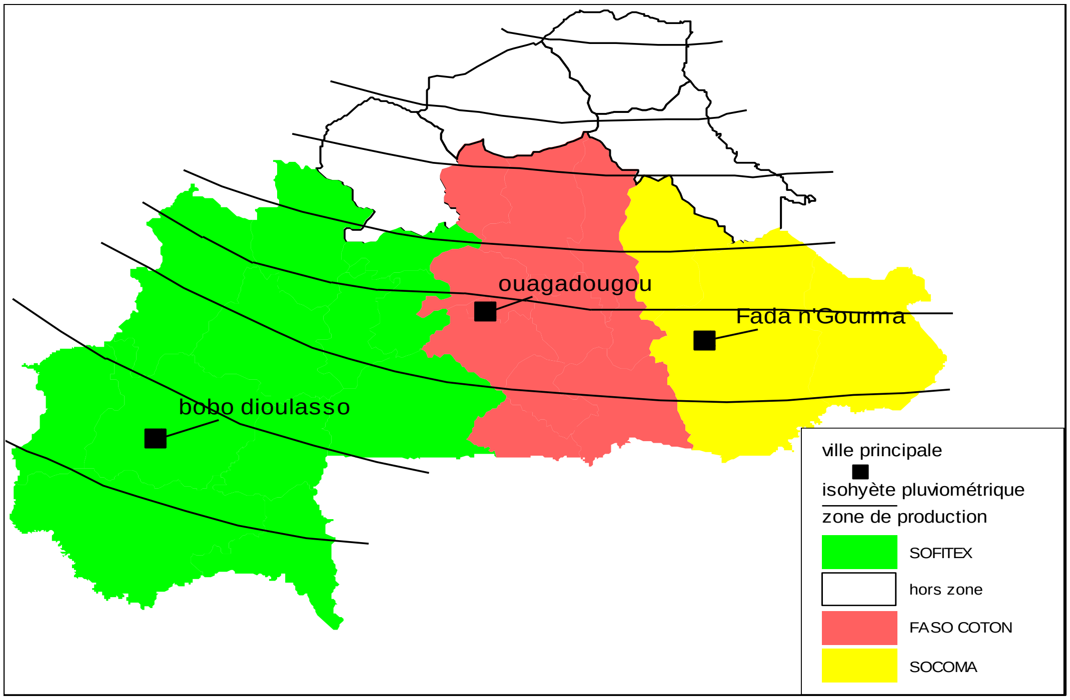

Figure 2. The three cotton zones of Burkina Faso.

of the country (Ouedraogo, 2006):

(1) The south Sudanese zone, located at the south of the 11°30' parallel with an average annual rainfall between 900 and 1200 mm. The rainy season here lasts six months. This is the domain of gallery forests along the rivers.
(2) The Sudano-sahelian region is situated within the 11°30' and 14°00'N parallels. This zone has an average annual rainfall of between 800 and 900 mm during four to five months. Here, there are more dense forest formations, and the herbaceous cover is more continuous. This is the largest zone and the one which is the most affected by human activity.
(3) The Sahelian zone is situated in north of 14°00'N. This zone has an average annual rainfall of between 300 and 600 mm and lasts for only three months. The vegetation there consists of steppes with trees, shrubs and thick bushes.

Study region: West of Burkina Faso

Zones of cotton production

The western region of Burkina Faso is the principal region of cotton production. In 2006, the production of cotton in the country was estimated at 676,065 tons, and the total amount of cotton farms was estimated at 325,000 ha. These farms are divided into three cotton producing zones in the country (Figure 2): the cotton zone of SOFITEX (Burkina Faso Textile Fibre Company) located in the west is the largest with 87% of national cotton production, the cotton zone of FASO COTON (Cotton company of Burkina Faso) located in the center with 8% of the production and the cotton zone of SOCOMA (Cotton Company of Gourma) located in the east with 5% of the production.

The cotton zone area of SOFITEX was chosen as the region of study for several reasons. One reason is that the region is the principal and historical area of cotton production. Furthermore, there are long series of reliable data for analysis in this region. The time series data for the other two sites is relatively short for the purpose of statistical analysis.

Temperature and rainfall in the western of Burkina Faso

Over the past 45 years, the shift in temperature is obviously less dramatic than the shift in rainfall. In the Figure 3, total rainfall and monthly average temperature of the cotton growing season (May to October) in the western of Burkina Faso are presented. There is an increasing trend of temperature for the last 45 years, which is not seen in rainfall.

Functional form of the regression model

The choice of variables to include in the regression analysis is crucial for the validity of the model. In the literature, temperature and rainfall have been demonstrated to have significant impacts on crop yields. Agronomically, high temperature affects soil moisture levels which could decrease crop yields if the supply of irrigation water supply is not sufficient. On the other hand, precipitation maintains necessary soil moisture for crop growth. Shifts in temperatures could change growing season lengths, thus inducing variations in crop yields. For example high temperature tends to shorten many crop growing seasons. A short growing season exposes crops to less solar radiation needed for photosynthesis (Caï, 2011).

The effects of weather conditions on crop yields are not simple linear relationships (Deschenes and Greenstone, 2007; Schlenker and Roberts, 2009). Most recent studies have adopted a non-linear specification for each climate variable where linear and quadratic terms are used as regressors, reflecting the effect of a physiological optimum on yield (Yingjie, 2008; Chang, 2002; Schlenker et al., 2009). This approach also allows a non-monotonic relationship

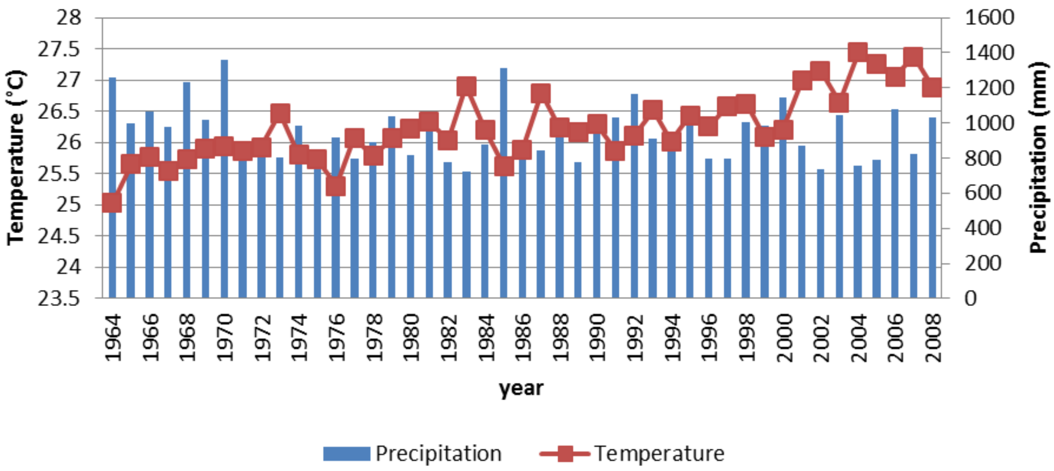

Figure 3. Total rainfall and monthly average temperature of the growing season of cotton (May to October) in western of Burkina Faso.

between climate and yield; warming might increase crop yields in cooler areas but decrease yields in warmer regions (Segerson and Dixon, 1999).

Besides the mean value of weather indicators, climate change has effects crop yields. Previous studies (Shaw et al., 1994; Mendelsohn et al., 1999) have shown that omitting the variation terms biased the effects of global warming; Chang (2002) included these two climate variation terms to estimate the potential impact of climate change on Taiwan's agriculture.

Crop yields do not depend only on weather conditions. Other factors can also affect crop yields such as crop prices. Several econometric studies provide evidence of the responsiveness of crop yields to crop price (Choi and Helmberger, 1993; Yingjie, 2008). The type of agricultural equipment and the level of intensification can also explain variability in crop yield (Huang et al., 2010).

Crop yields are expected to increase over time because of technological innovations such as the adoption of new varieties, improved application of fertilizers and irrigation, and expansion or contraction of crop acreage. Technological innovation is usually represented by a linear or quadratic time trend in empirical studies (Choi and Helmberger, 1993; Kaufmann and Schnell, 1997; Mc Carl et al., 2008).

Determinant of cotton yield in Burkina

Cotton yield response is typically estimated from field data using measurement of climate and non-climate-related variables to identify the physical effect of climate change on yield. In this study, the growing season (May to October) was divided into growing stages (S). The first stage is the planting time and germination (1st May to 30th June), the second is the vegetative growth (1st July to 1st September), the third is the development of fruiting and vegetative branches (1st September to 30th September) and the forth is maturity (1st October to 30th October).

The explanatory variables include: T_s, decadal average temperature of growing stage (°C); R_s, decadal average rainfall of growing stage (mm); VT_s, standard deviation of decadal temperature of the growing stage; VR_s, standard deviation of decadal precipitation of the growing stage; P_c, current price of cotton with regard to fertilizer price and D, time trend to consider technical progress. The average annual yield Y is the dependent variable (Equation 1):

$$Y = f(T_s, T_s^2, R_s, R_s^2, VT_s, VR_s, P_c, D) \tag{1}$$

This model adopts a non-linear specification for each climate variable where linear and quadratic terms are used as regressors, reflecting the effect of a physiological optimum on yield. Changes in temperature and rainfall from historical values are also included to capture the effect of an extreme event on yield. The model is estimated with time-series data over the period 1964-2008.

The samples consisted of secondary data for the western of Burkina Faso corresponding to SOFITEX company area. The data for average cotton yield (kg/ha), annual price of cotton (FCFA/kg) and annual price of fertilizer were provided by the SOFITEX Company. Decadal weather data on temperature and rainfall were obtained from the Burkina Central Weather Bureau. Temperatures are in degrees Celsius and rainfall measured in millimeters.

The summary statistics are presented in Table 1. Over the past 45 years, the temperature shift is obviously less dramatic than the variation in rainfall.

RESULTS AND DISCUSSION

Estimation of the cotton yield regression model

The model was estimated using SAS statistical analysis. The results show that the explanatory variables have significant effects on cotton production and the model tends to have a good explanatory power as measured by the coefficient of determination (R^2 = 0.94). The Durbin Waston coefficient (d=2.3) is close to 2, therefore errors are not correlated.

The results of coefficients of the explanatory variables are given in Appendix 1. Table 2 shows the variability of cotton yield in response to climate and non-climate variables.

For the non-climate variables, the coefficients of the explanatory variables have the expected sign. The relative price of cotton has a positive and very significant impact

Table 1. Summary statistics of data used in cotton yield response regression.

Parameter	Mean	Standard error
Non-climate		
P_c	0.93	0.21
Climate		
T_1	28.0	0.72
T_2	25.0	0.55
T_3	25.17	0.64
T_4	27.0	0.75
R_1	157	109.2
R_2	321.6	207
R_3	131.6	72.3
R_4	44.2	33.0
Climate shifts		
VT_1	2.3	1.20
VT_2	0.4	0.27
VT_3	0.6	0.4
VT_4	0.55	0.46
VR_1	743.2	469.43
VR_2	2043.2	1662.36
VR_3	1204.3	1146
VR_4	442.6	567

Table 2. Variability of cotton yield in response to climate and non-climate variables.

Variable	Growth stages	Variability
Temperature	First	-1.32
	Second	-4.14
	Third	5.30
	Fourth	1.60
Rainfall	First	0.18
	Second	-0.04
	Third	0.03
	Fourth	0.04
Relative price		0.93
Time trend		0.44

on yield. More specifically, a 1% increases in the relative price of cotton increases the average yield of cotton by about 0.93%. Fertilizer use is very important for cotton. It can represent up to 60% of production cost. Technology, represented by a time trend has as expected a positive and significant effect on cotton yield.

For the climate variables, increasing temperature in the two first growing stages is mostly unfavorable for cotton yield, while it is favorable in the two last ones, particularly the third stage. Too much rain in the second stage is unfavorable for cotton yield but favorable in the three other stages. A number of studies have determined the impact of climate change on cotton yield using the data from field and/or laboratory controlled-experiments and various crop simulation models. The result of the relationship between rainfall and cotton yield is quite consistent with the results in Some et al. (2006). That study used a crop simulation model and concluded that at the end of the rainy season cotton needs irrigation to reach its potential yield.

Climate changes have an impact on cotton yield. Our results show that rainfall variations of the last growing stages have a significant and negative impact on yield. Temperature variation of the first growing stage has significant and unfavorable impact on cotton yield. The review by Adams et al. (1998) compared the climate effects on grain crops in Latin and North America stemming from various crop simulation models. Their comparison indicated that crop productivity in large areas of Latin America is negatively affected by the inter-annual variability and the occurrence of extreme events.

Specific climate change cases for Burkina Faso

Strzepek and Mc Cluskey (2006) have developed climate evolution models for many African countries that cover the period between 2050 and 2100 within the framework of the hydrology component for the Global Environment Facility of the World Bank. These models are based on the A2 and B2 scenarios of the Special Report on Emissions Scenarios (SRES) and provide specific forecasts by country. All models forecast a rise in temperatures for Burkina Faso. This increase will vary from 2.4 to 3.9°C in 2050 and from 5.7 to 9.7°C in 2100 for the A2 scenario. The B2 scenario projects an increase of between 2.4°C and 3.8°C in 2050 and between 4°C and 7.1°C in 2100. While both scenarios indicate a potentially serious climate change impact in Burkina Faso, the latter scenario looks less alarming.

The models provide the same forecasts for rainfall regardless the scenario (A2 or B2). Four of the five models predicted an increase in rainfall from 1% to 12% by 2050 and from 3% to 30% by 2100. Only one model foresees a decrease in rainfall of about 4% by 2050 and 9% by 2100.

In our analysis, we assume that future temperature will increase by 0.5 to 4°C while future rainfall will change by -20 to 20%. The effect of precipitation variability is also estimated.

Impact of climate change on cotton production

Because the data used in this study do not result in an estimation of the effects of changes in CO_2, all scenarios describe no change in the CO_2 level and thereby include no CO_2 fertilization effects. Therefore, it was also assumed that the temperature or rainfall change occurs in all the four growing stages. Thus, in each scenario all seasonal variables are adjusted simultaneously by the same amounts.

The observed effect of the likely future change in climate (temperature and precipitation) on crop yields is shown in Figure 3. The results show that when temperature increases by 1°C cotton yield increases to 3% relative to the mean yield but decreases when temperature is higher. It can be concluded that higher temperature is harmful for cotton production. Similar results have also been reported by Schlenker and Roberts (2009) for U.S cotton production. Using an extensive 1950-2005 county level panel regression for the Eastern U.S. and fixed-effects models, they find that yields increase with temperature up to 32°C for cotton, but that temperature above these thresholds are harmful. They predict that a 4°C increase in temperature can lead to cotton yield decrease by 25%. The result shows a decrease of 13% in cotton yield for 4°C increase.

Using the growing season temperature and employing the Just and Pope (1978) stochastic production function, Schimmelpfennig et al. (2004) examined state-level panel data and found that cotton yields is adversely affected by growing season temperature. Reddy et al. (2002) used crop simulation models to estimate the impact of climate change on cotton production in the State of Mississippi, United States, and concluded that if global warming occurs as projected, fiber production in the future environment will be reduced. In Zimbabwe, Gwimbi (2009) examined climate change and its impact on cotton production using a time series analysis of temperature and rainfall for a period of 30 years. That study found that cotton production levels declined as rainfall decreased and temperatures increased throughout the district.

The effects of future changes in rainfall show that a higher rainfall could lead to an increase of cotton yield (Figure 4), while a 20% reduction in precipitation will decrease cotton yield by 4.4 and a 20% increase in precipitation will increase yield by 3%. Compared with the effects of temperature, the effects of rainfall are relatively small.

Table 3 lists 5 combinations of alternative climate change cases, which include 0, +4°C for temperature and -20, 0 and +20% for precipitation. The scenarios of decreasing rainfall (-20%) and increasing temperature (+4°C) will be highly deleterious to cotton production, leading to a cotton yield decrease of about 17.7%. The impact will be severe and harmful because Burkina Faso's climate is already relatively hot and dry.

Economic impact of change in cotton yield

The chain value approach was used to evaluate the impact of changes in crop yield on farmers' gross income, foreign exchange earning and tax revenues. The data used is from a report on the cotton sector made by the Ministry of Agriculture of Burkina Faso (MAHRH, 2007) for the 2005 seasonal year (Table 4).

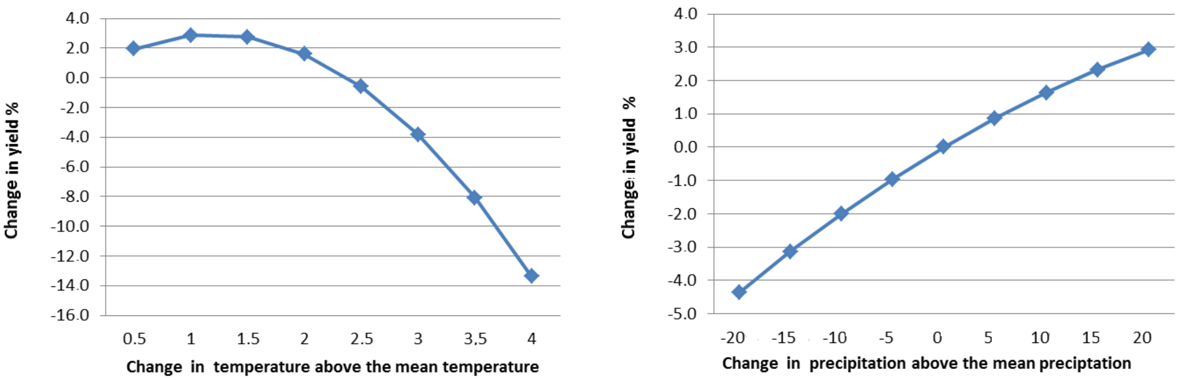

Figure 4. The impact of projected climate change on Burkina Faso cotton yield.

Table 3. Change in cotton yield according to scenario.

Scenario	Temperature (°C)	Precipitation (%)	Yield change (%)
1	+4	-20	-17.7
2	+4	0	-13.4
3	+4	+20	-10.5
4	0	-20	-4.4
5	0	+20	+2.9

Table 4. Change in income and foreign exchange from 2005 data base.

Scenario	Farmer ‘gross income change (%)	Foreign exchange earning change (%)
1	-38	-17.7
2	-29	-13.4
3	-23	-10.5
4	-9	-4.4
5	+6	+2.9

As might be expected, the impact of climate change is very harmful for farmers income and the Burkinabe Faso economy. The findings of Kurukulasuriya and Mendelsohn (2008), Deressa and Hassan (2009), Molua and Lambi (2007), and Gwimbi (2009) also revealed that decreased rainfall or increased temperatures reduce cotton yield, which led to a reduction in net revenues in Africa. These results were also confirmed by the findings in Ouedraogo et al. (2006) in which the Ricardian approach was used to evaluate the relationship between net farm values and climate change. Indeed, they found that if temperature increases by 1°C, revenue will fall by US$ 19.9 ha^{-1} and if precipitation increases by 1 mm/month, net revenue increases by US$ 2.7 ha^{-1}.

Conclusion

In this paper the impact of climate change on cotton production in Burkina Faso was evaluate because cotton production is a major source of foreign revenue and a key sector of the national economy. An econometric analysis enabled the identification of the major factors influencing cotton yields and the evaluation of the likely effects of future climate change. As compared to other studies, this study includes a more comprehensive set of climate and socioeconomic variables.

The results show that cotton yield responds positively to the relative price of cotton. It was also shown that climate variables impact cotton yields. Increasing temperature in the two first growing stages is mostly unfavorable for cotton yield, while it is favorable in the two last stages. Too much rain in the second stage is unfavorable for cotton yield but favorable in the three other stages.

The simulated results regarding the potential impact of future climate change on cotton yield clearly indicate that further increases in global temperature would significantly reduce the yield of cotton. Future changes in rainfall would also affect cotton production, however compared with the effects of temperature, the effects of rainfall is relatively small.

For the last few decades, research in Africa has focused only on drought resistant cultivars. This strategy may not be sufficient according to the results of this study. Therefore, strategies for reducing the impacts of climate change on cotton production should emphasize on the development of heat resistant cultivars rather than drought resistant cotton cultivars in order to mitigate and adapt to the effects of climate change.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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