THE Effects of Drought on Crop Yields and Yield Variability in Sahel

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I: Introduction

Global climate change is no longer an assumption. The increasing concern about the costs associated with global warming has catalyzed an economic rethinking on climate change. More importantly, recent studies have shown that the increase emission of greenhouse gases is the main cause of changes in climate conditions such as increase in temperature, irregularity and reduction in rainfall in some areas, a rise in floods and prevalence of hurricanes in other areas, and the increase in the number of tornadoes (Houghton et al. 1996, Schimmelpfenning et al. 1999). Various studies (IPCC, 2007) have pinpointed Africa to be one of the most exposed continents to suffer the devastating effects of climate change and climate variability, with colossal economic impacts. The African rain-fed agriculture is viewed by many observers to be the most vulnerable sector to climate variability. A number of African countries structurally experience semi-arid conditions, with very little agricultural production and thus rely on import of foodstuffs. IPCC (2007) predicts a reduction of 50 percent in yield by 2020, and a fall in crop net revenues of 90 percent by 2100 in already marginally agricultural regions. If these dismal predictions come to realization, then most of Sahelian countries will cease agricultural production. The yield trend of the three major crops in Sahel is given in Figure 1 below.

[Place Figure 1 approximately here]

The graph shows a dramatic variation in yield with no significant upward trend, except for maize yield.

A number of previous studies have estimated the impacts of climatic change on the economy in general, and the agricultural sector in particular. Those impact studies have progressed in two directions. The first group uses simulation methods¹ (Williams et al. 1998; Aggarwal and Mall, ¹ See Wang, 2005 for an extensive review of literature of the studies using a simulation method to investigate the effects of climate change on crop yields.
2002; Mearns, Rosenzweig and Goldberg, 1997; Wang, 2005). As for the second group, regression models are estimated for specific crops (Cheng et al., 2004; Isik and Devadoss, 2006; McCarl et al., 2008), farmers’ revenues (Deschenes and Greenstone, 2007) or land values (Mendelsohn et al. 1996).

Until recently, most of climate change agricultural impact studies have been concerned solely with the effects on mean changes of crop yields. Mearns et al. (1997) argue that the information provided by studies focusing only on mean changes and neglecting changes in variability on crop yields is limited. The existence of little empirical evidence on crop yield due to variations in climatic conditions has placed a strain on the information provided by the impacts of changes in temperature and precipitation. Thus, uncertainties still remain with regard to the estimates of the parameters of climate variables in yield production functions. However, reliable estimates are necessary in order to provide useful insights into the effects of changes in temperature and precipitation. Such information would also be useful in assessing mitigation policies. This paper will contribute to the existing literature by focusing on a drought-prone region in West Africa, and where the agricultural sector remains the main source of employment for more than 90 percent of the rural population (World Development Indicators). Commonly referred to as Sahel, the region has been the major locus of droughts during the past four decades. Moreover, in Sahel as is the case of many African countries, on average, less than 1 percent of cropland is irrigated. According to IPCC (2007), factors such as endemic poverty, bureaucracy, lack of physical and financial capital, frequent social unrest and ecosystem degradation contribute to Africa’s vulnerability to climate variability.

A clear assessment of the effects of climate variability in a semi-arid zone is a handy policy tool. Most African countries rely on the agricultural sector to foster their economic growth (Barrios et al., 1997) for a detail analysis of impact studies of climate change on fluctuations on yield.
Agricultural production plays a key role in Sahel’s economy. It is a critical mainstay livelihood at the individual scale and at the national level as well. The agricultural sector employs around 58% of the labor force in Sub-Saharan Africa (FAOSTAT, 2005). In contrast, Sahelian countries present a much larger figure. Indeed, about 80% of the population in Sahel depends on agriculture as their main source of employment. For the region as a whole, the agricultural sector is considered to be dualistic with millet, maize and sorghum destined for subsistence and cotton and groundnuts being the cash crops (Thiele, 2003).

The share of the agricultural sector in the national gross domestic product (GDP) varies across countries. It ranges from 17.2% in Senegal to 62% in Guinea Bissau (World Bank, 2000). While Sahel’s dependence on agriculture has been growing over time, evidence suggests that the productivity of the sector has declined (Sultan et al., 2004). Moreover, despite its large share of agricultural population, Sahel relies heavily on imports of foodstuffs, an ironic situation when compared to the United States where only 3% of the populations are farmers, but they provide up to 17.14% of the world production of cereals (FAOSTAT). Sahelian countries are in general agrarian economies; therefore, the study of the economic impacts of climate variability can be done from the perspectives of the agricultural sector without loss of generality.

The purpose of this paper is to analyze the impacts of droughts on the mean and variance of crop yields, and to examine the implications of climatic change on agriculture in eight Sahelian countries of West Africa. I estimate stochastic production functions by regressing crop yields on precipitation, temperature and land variables. One of the strengths of this paper is the use of the Standardized Precipitation Index (SPI) and the precipitation intensity index as a proxy for precipitation and the degree-days to account for the effects of temperature. By doing so, this

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3 This is an improvement over previous studies that used mean annual temperature and average precipitation as their climate variables.
project will contribute to the existing literature on impact studies of climatic change. The econometric model reveals that an increase in temperatures and a poor spread of rainfall throughout the growing season have a damaging impact on the mean of crop yields, and simultaneously, an increase in precipitation (or a reduction in the severity of drought) is beneficial to crop yields. Furthermore, I find evidence that precipitation and temperature are risk-increasing in maize production. In contrast, precipitation is risk-increasing and temperature is risk-decreasing in millet and sorghum production.

Avowedly, several other factors such as genetic characteristics of seeds, solar radiation, soil moisture, pest situation, fertilizer may also affect crop yields, especially in Sahel. However, I am unable to find time series data on the aforementioned variables for specific crop yield.

The remaining of this paper is organized as follows: Section II reviews the relevant literature. The data and the methodological framework are discussed in section III. In section IV, I analyze the empirical results. Finally, the concluding remark and policy implications follow in section V.

II: Drought Impacts: View from previous literature

Climate conditions such as storms or droughts are said to have staid social impacts (e.g. famine, population displacement) as well as long lasting economic distresses (e.g. pauperization of rural population), thus jeopardizing any plausible objectives of socio-economic development envisioned by the countries exposed to the cataclysm (Lecocq and Shalizi, 2007).

This dire prediction of droughts as a climatic calamity has prompt researchers to assign a role for economics into the climate change debates. The surge in scientific research in climate change has led to a consensus about some aspects of the phenomenon. In effect, well respected research in the field shows that the accumulation of greenhouse gases in the atmosphere will ultimately alter the world’s climate in the form of increase in temperature, change in frequency and amounts of
rainfall or increase in the number and intensity of storms (Houghton et al. 1996, Schimmelpfenning et al. 1999).

The issue of how harmful changes in climate will be is still unsettled as the results presented by past studies are mixed. For example, Rosenzweig (1989) uses general circulation models (GCMs) to predict an increase in global mean temperature ranging from 2.5 to 5.5 °C dependent on regions and other parameters. However, he acknowledges that other researchers have used GCM and reached different conclusions regarding global warming and the associated changes in precipitation. He reports that Manabe and Wetherald (1987) and Kellogg and Zhao (1988), among others, have used GCMs and found a drying of soil moisture during mid-continental summer. Put differently, when regional disparities are taken into consideration, then an increase in temperature will have different results on different regions of the World.

To shed light on the substantial consequences bestowed by climate variability, some researchers have analyzed the phenomenon from the economy-wide perspective. From that angle, Benson et al. (1998) present the findings of an exploratory case study of six countries (Burkina Faso, Ethiopia, Kenya, Senegal, Zambia and Zimbabwe). They seek to discuss strategies believed to help the affected countries lessen the economy-wide impacts of drought. The authors purport that about 60 percent of Sub-Saharan Africa is exposed to drought and 30 percent so extremely. Part of the Sahel and Southern Africa fall in the latter group. Benson et al. (1998) suggest that “the prospects of an El Nino effect has led to more focus on the impact of drought in Sub-Saharan Africa.” The main findings of the report indicate the existence of a more complex association between the effects of drought and a country’s economic structure. Specifically, in a simple economy as one with a limited infrastructure, comprising a high proportion of poor rural

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4 This situation rhymes well with the condition in Sahel where all the precipitations are received only during the summer season.
5 Sahelian Countries
population and where agriculture is predominantly rain-fed\textsuperscript{6}, drought may have a very pronounced adverse impact because of the relatively important role of the agricultural sector in the whole economy and the lack of appropriate mitigation strategies.

A decade later, in a relatively wider perspective, Dell et al. (2008) use annual variations in temperature and precipitation over this past half century to study the impacts of climate change on the world economy. They find an overall lack of any apparent harm to the world economy due to climate change. The authors explain their findings as follows: Firstly, the change in precipitation has no effect on the world economy.\textsuperscript{7} Secondly, although an increase in temperature will affect poor countries, it has no effect on developed countries. And since the bulk of the world countries are rich, then the overall result will be positive. They derive their startling conclusion on the basis of the transmission mechanism of climate change on economic activities which shows a negative relationship between temperature and agricultural output, industrial output and growth in investment in poor countries.

Prior studies have found a negative association between climatic change and economic outcomes even in developed countries, however. For example, Marangos and Williams (2005) purport that the increased uncertainty resulting from drought has a negative effect on the level of investment planning and infrastructure which in turn hinder economic growth in Australia.

The above mixed results bring out that aggregated studies of the effects of climate change neglect to account for differences in international productivity, socioeconomic environment or country structure as pointed out by Lang (2000). Common sense suggests that warmer countries will suffer more from an increase in global temperature and colder countries will benefit from it. Also, like temperature, the effects of rainfall abnormality will be different worldwide. While

\textsuperscript{6} This is the case of Sahelian countries.

\textsuperscript{7} Poor countries and developed countries alike.
some countries (mostly poor countries) are at the mercy of nature, other countries are better equipped to lessen the negative impacts of rainfall irregularities (e.g. through irrigation or proper mitigation strategies). In poor countries, most of the effects of climate change will be seen through the agricultural sector because of its importance in the economy. For example, Dell et al. (2008) predict that in poor countries, unlike rich ones, higher temperatures will have far-ranging negative effects in terms of reduced economic growth rates as well as a loss of output. Their estimates suggest that an annual increase in temperature of 1 °C will reduce the annual growth rate by almost 1 percentage point in poor countries. In contrast, they find no perceptible economic growth effects in rich countries. From the perspectives of developed countries, Deschenes and Greenstone (2007) estimate the effects of year-to-year random variations in temperature and precipitation on agricultural profit of U.S. farmers. At the national level, their estimates indicate that climate change will increase farmers’ profit by 4 percent. However, this overall effect hides significant dissimilarities across the country. The state level estimates predict that an increase in temperature and precipitation will harm California, Nebraska and North Carolina on one hand, and on the other hand Georgia and South Dakota will be the two biggest winners.

Claiming to improve the methodology used to analyze environmental events, Sherony et al. (1991) make use of a computable general equilibrium (CGE) approach to study the impact of the 1988 drought on crop yields and management practices. They analyze the interactions of supply and demand within the agricultural market, and also between that market and the rest of the economy. By incorporating the resulting crop losses and increase in management costs into the CGE model, they isolate the individual impact on the agricultural sector, agricultural-related industries and the overall economy. They conclude that crop losses as a result of environmental
change can only marginally increase retail food prices and the general price level in the economy.

In a holistic approach covering effects on agriculture, sea level, human health, forestry, natural ecosystems, water resources and energy consumption, Tol (2002) studies the market and non-market damages caused by climate change.\(^8\) Under the sweeping assumption of an increase of the global mean temperature by 2.5\(^\circ\) C, he predicts that the gross agricultural product of African countries will either increase by 0.47 percent or fall by 0.23 percent depending on whether farmers’ adaptation to climate change is taken into consideration.

Wang et al. (2008) analyze the effect of temperature and precipitation on net crop revenues using a cross section data on both rain-fed and irrigated farms in China. Using a Ricardian analysis, they find higher temperatures to be harmful, and more precipitations to be beneficial to the agricultural production. In contrast, their most disaggregated results show that “marginal increases in temperature and rainfall have different effects on different farm types in different regions”. Similarly, Mendelsohn et al. (2006) find different impacts of climate change on different regions of the world. To project the distributional impacts of climate change, they divide the world into four groups of countries based on their projected 2100 per capita income. Their results, based on six different climate scenarios, indicate that the poorest half of the world’s nations bears the bulk of the damages of climate change, while the wealthiest quarter shows no detectable sign of effects.

It becomes clear that change in climatic conditions may exacerbate the struggles of poor countries. In the following section, I will concentrate on the specific case of African countries.

\(^8\) However, Mendelsohn et al. (2006) argued that no reliable estimates of the magnitude of welfare impacts of non-market effects of climate change exist yet.
2.1: Drought and African countries:

From the perspectives of geographic location, African countries, as many other developing countries, are considered to be highly vulnerable to climate change and climate variability as their economies are largely based on weather sensitive agricultural production system (Sultan et al., 2004). In the case of Sahel, this vulnerability is worsened by prolonged and widespread droughts since 1968. Another reason of African vulnerability to climate change is its low substitution possibilities between imported and domestically produced cereals (Winters et al., 1998). The aforementioned factors that contribute to Africa’s vulnerability to climate variability are worsened by endemic poverty, bureaucracy, lack of physical and financial capital, frequent social unrest and ecosystem degradation (IPCC, 2007). Despite the recognition of the potential negative effects of environmental damages, not only are economic studies addressing the problem scanty as compared to those in developed countries, but little is known about the magnitudes of the impacts on Africa.

The agricultural sector is the major source of employment in Sahel. Even though the agricultural performance is in question, the share of the sector in GDP still is substantial. Despite the prevalence of recurrent droughts, the agricultural sector is the main economic activity in Sahel.

In general, study on agricultural productivity growth in less developed countries (LDCs) has not received as much interest as in developed countries (DCs) (Winters et al., 1998). At the time when the agricultural productivity in Africa was being debated in an anecdotal manner, Block Steven (1994) published his article using data spanning from the period of 1963 to 1988. Block finds gains in productivity in 1960s, regression in 1970s, and recovery in 1980s. He attributes the recovery to improved weather conditions, macroeconomic and sectoral policy reforms and to a lesser extent technical change.
The milestone paper by Block (1994) was just the starting point of a scientific debate about the performance of the agricultural sector in Africa. Comprehensive studies on agricultural productivity in SSA covering different periods in different set of countries have looked at such factors as R&D expenditures (Lusigi and Thirtle 1997), macroeconomic policy (Thiele, 2003) or the role of institutions (Fulghiniti et al., 2004)\(^9\) to name a few. To study the economic impacts of droughts, Le Nay and Mathis (1989) analyze the impact of the 1984 drought on national accounts in two Sahelian countries (Niger and Mali). Specifically, they look at the methods used by both countries in measuring livestock production and compared those methods to the ones used by the United Nation System of National Accounts (UN SNA) adjusted for the existence of drought. They conclude that drought has a ravaging impact on livestock but the magnitude of the disaster is sensitive to the type of measurements used. A few years later, using survey data, Sakurai (1997) examines crop production under drought risk and demand for virtual drought insurance in Sahel. His panel data covers the period from 1981 to 1984 with a sample of 89 households in Burkina Faso. His model specification is a modified Cobb-Douglas function with interaction terms between traditional inputs and a drought variable which is defined as a year with precipitation lower than the long-term average. This faulty definition of drought has been widely used in most of the impact studies of climate change. Along those lines, Thiele (2003), using a co integration technique, estimates a long run relationship between agricultural production, price incentives and non price factors (including drought) in ten Sub Saharan African countries.\(^{10}\) His conclusion enhances the view that agricultural growth has been significantly hampered by drought episodes.

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\(^9\) Reference to drought in term of a dummy variable was made in their study; however it was not the subject of their paper.

\(^{10}\) Two of which are Sahelian countries (Niger and Burkina Faso)
The diverse conclusions reached by the previous works on either the agricultural productivity in Africa or the uncertainty surrounding the magnitudes of the estimates of the impacts of climate change make it clear that both issues are far from being settled. And major shortcomings with previous works can be summarized around several points:

For one thing, studying the agricultural productivity in Africa as a block is misleading because Africa is a large continent with diverse regions, and each region has its specific characteristics. For example, even within the Western part of Africa, some countries like Mali, Mauritania, or Niger suffer from recurrent droughts, while other countries like Liberia, Sierra Leon or Ivory Coast are relatively wet.

Secondly, of the small number of previous studies that analyze the sluggish agricultural productivity in Africa, only a few have mentioned the possible role of climate change and climate variability. Most of the global studies provide few details about how and why African countries will be adversely impacted by the increase in temperature or a decline in precipitation. Most importantly, previous impact studies fail to spark the debate on the economic impacts of droughts. At best, their proxy of the drought variable is a year-to-year variation in precipitation. Alternatively, they either reference a drought year based on a subjective assessment by country experts (Le Nay and Mathis 1989; Roncoli et al. 2001; Little et al. 2006) or they use a dummy variable (Fulginiti et al., 2004; Thiele, 2003). Clearly, there is a problem with the previous handling of drought variable. For one thing, a year-to-year variation in precipitation or a downward deviation from a historical average does not fit even the simplest definition of drought. Moreover, the use of average precipitation implicitly assumes that rainfall distributions follow a symmetric distribution, which is not true. A cursory look at any precipitation records reveals that rainfall distributions are skewed with lower amounts being more frequent. Secondly,
with respect to the use of a dummy variable, the primary flaw is that the researcher does not fully exploit all the available information. For example, setting the dummy variable equal to one for drought and zero otherwise means that the researcher acknowledges the existence of only two states: drought or no drought. In reality, almost all the drought indices recognize several relative meteorological states: severe drought, extreme drought, near normal, extreme wet and very wet (e.g. SPI, PDI). More importantly, the most well respected statistical studies argue that the misuse of dummy variables in regression analysis will yield biased parameter estimates (Polissar and Diehr, 1982).

Thirdly, from a global perspective, previous studies on the effects of climate change (either using the cross sectional approach or the simulation methods) have been inconclusive with regard to the sign and the magnitude of the impacts.

**III: Data and Methods**

3.1: **Empirical Model**

The bulk of previous works on climate change either employ the crop simulation methods or use the cross sectional hedonic approach and its variants to infer the magnitudes of the impacts. A critical examination of the merits of both methods used in analyzing the issue at hand raises some points of concern. The general circulation models (CGM), also known as the global climate models, are used to numerically simulate changes in climate resulting from changes in physical conditions such as greenhouse gases. It has been argued that even a small change in atmospheric conditions is enough to cause the GCM to perform poorly.

The use of cross sectional model to predict the impacts of climate change is not exempt from criticism. For example, the Ricardian model pioneered by Mendelsohn (1994) measures directly the impacts of climatic change on land value. Critics of this widely used method, Deschenes and
Greenstone (2007), argue that omitted variables (e.g. the possibility to convert a land to a non-agricultural use) resulting from unobserved characteristics of land are key determinants of output and land value. Thus, the Ricardian model may produce some biased estimates.\textsuperscript{11} Change in land values may not accurately reflect change in climate conditions. Also, any aspects of future climates that differ from the present conditions will not be accounted for in the Ricardian model.

To capture how climate change and climate variability could affect the agricultural sector, a recent wave of studies looks at the effects of change in climate variables on crop yields. Along this line of thought, researchers such as Chen, McCarl and Schimmelpfennig (2004); Isik and Devadoss (2006) have used production risk, also known as stochastic production function developed by Just and Pop (JP) (1978).

The JP model is generally expressed in the following form:

\[ Y = f(X) + h(X)^{1/2} \epsilon, \ E(\epsilon) = 0, \ V(\epsilon) = 1. \]

Where \( Y \) is output, \( X \) is a vector of inputs, and \( \epsilon \) is a stochastic disturbance.

The idea behind the above specification is that the effects of inputs on output should not a priori be tied to the effects of inputs on the variability of output.

The first argument of equation (1) specifies the effects of inputs on the mean of output and the second argument expresses the effects of inputs on the variance of output.

Thus \( E(Y) = f(X) \), and \( V(Y) = h(X) \) and the two effects are independent.

For the purpose of this paper, I will follow Isik and Devadoss (2006) and develop the following econometric model:

\[ Y_{ijt} = f(X_{ijt}; \alpha) + \mu_{it} \]

\[ \mu_{it} = \epsilon_{it} h(X_{ijt}; \beta)^{1/2} \]

\textsuperscript{11}To all fairness, see Deschenes and Greenstone (2007) who pointed out some advantages as well as the disadvantages of both methods.
Where $Y_{ijt}$ is the $j^{th}$ crop for country $i$ at year $t$; $X_{ijt}$ is the $j^{th}$ input used by country $i$ at year $t$; $\varepsilon_{it}$ is an error term with mean zero and variance equals to 1 to ensure positive output variance (Isik and Devadoss, 2006). $\alpha$ and $\beta$ are parameters to be estimated. Since the expected crop yield is

\[ E(Y_{it}) = f(X_{it}; \alpha), \]

and the variance of crop yield is given by:

\[ V(Y_{it}) = V(\mu_{it} | X) = V(\varepsilon_{it}) \ast \exp( h(X_{it}; \beta)) = \exp( h(X_{it}; \beta)), \]

then the estimates of $\alpha$ and $\beta$ give the effects of the independent variables on the mean crop yield and the variance of crop yields respectively.

The model expressed in the form of equation (2) has traditionally been estimated using either Feasible Generalized Least squares (FGLS) or maximum likelihood (ML) procedures following Just and Pope (1978, 1979).

### 3.1.1: The Feasible Generalized Least Squares Estimation (FGLS)

The FGLS estimation is carried out using a three step procedure. Firstly, from equation (2), $f(X_{ijt}; \alpha)$ is estimated via ordinary least squares. Secondly, the log of the squared residuals, $\hat{\mu}_{it}^2$ from the first step are used to obtain the estimates of parameters, $\hat{\beta}$, in the variability portion of the model in equation (3). Specifically, one should proceed as follows:

\[ \ln(\mu_{it}^2) = \beta_0 + h(x_i, \beta) + \varepsilon_{it} \]

Equation (5) can be consistently estimated by least squares (Saha et al., 1997).

The third step is the weighted least squares estimation of the first argument in equation (2) using the antilog of the predicted value of the residuals obtained from the second stage as weight.
(6) \[ y_i^* = f^*(x_i, \alpha) + \mu_i^* \]

Where \( y_i^* = y_i \cdot \text{Exp}(h(x_i, \beta)^{-1/2}) \cdot f^*(x_i, \alpha) = f(x_i, \alpha) \cdot \text{Exp}(h(x_i, \beta)^{-1/2}) \), and

\[ \mu_i^* = \mu_i \cdot \text{Exp}(h(x_i, \beta)^{-1/2}) \]

Saha et al (1997) reported that Amemiya (1985), and Jobson and Fueller (1980) demonstrated that \( \hat{\beta} \) and \( \hat{\alpha} \) are consistent estimates.

3.1.2: The maximum Likelihood Estimation (MLE)

Under the assumption \( \epsilon_{it} \sim \text{N}(0, 1) \), the log-likelihood function of (2) is given by (Sala et al. 1997; Huang, 2004; Isik and Devadoss, 2006):

(7) \[
\ln L = - \frac{1}{2} \left[ N \cdot \ln(2\pi) + \sum_{i=1}^{n} \left( \frac{y_{ijt} - f(X_{ijt}, \alpha)}{\text{Exp}(X_{ijt}, \beta)} \right)^2 + \sum_{i=1}^{n} \beta X_{ijt} \right]
\]

where \( N \) is the number of observations, \( Y \) and \( X \) are defined as above, and \( \alpha \) and \( \beta \) are unknown parameters to be estimated.

According to Saha et al. (2004), the maximum likelihood yield consistent and efficient parameter estimates of \( \alpha \) and \( \beta \).

I estimate the stochastic production function of maize, millet and sorghum yields using both the three-step FGLS and the single stage ML procedures of the linear and the quadratic forms of equation (2). However, using Monte Carlo experiments, Saha et al. (1997) present an appealing argument that, for small samples, ML estimates are unbiased and more efficient than the FGLS estimates. Thus, this paper will focus on MLE.

3.2: Data and Descriptive Statistics
This empirical study examines the impact of drought on the agricultural sector in 8 Sahelian countries using data from 1970 to 2000. These countries are of interest because they share similar climatic conditions and socio-economic characteristics. The logic behind the choice of this starting date is supported by the idea that the noticeable decrease in precipitation in Sahel dates back to 1969. Three different crop yields are used as the dependent variables: maize, millet and sorghum. Those three are the main crops cultivated for subsistence in Sahel. Means, Maxima, minima and standard deviations of all the variables in the regressions are presented in Table 1. Crop yields are expressed in kg/ha. The variable temperature sends us two signals. First, the mean temperature is above 26° C, which is quite high. Second, there is little difference between the high of 29.3 and the low of 21.3. The information provided by the aforementioned two points is indicative that Sahel is a very warm region. The aridity of the region is better portrayed by the precipitation variable which shows a large variability between the maximum and the minimum values. This irregularity in the rain fall pattern is well translated into the yield of the three crops used in this study. The descriptive statistics suggest that the observed variability in rain fall may well explain the tumbling agricultural productivity experienced by Sahelian countries since the beginning of 1970s.

[Place Table 1 approximately here]

Droughts are recurrent and harsh in many African countries and especially in Sahel. The unpredictability of the rainfall combined with the aridity of the area result in Sahel being exceptionally vulnerable to the slightest decrease in precipitation or increase in temperature. All the climate models predict a worldwide increase in temperature. And in Sahel, the increase in temperature is likely to be associated with a reduction in rainfall. The summer season is the only rainy season in the region. Precipitation data show an erratic rainfall pattern, with more trough
than peak years. If the trend is to continue, then the region will likely see an increase in evapotranspiration, and therefore an increase in the severity and recurrence of droughts. Benson et al. (1998) give an economic definition of drought as “the impact of abnormally low rainfall, outside the normal expected parameters with which an economy is equipped to cope, on productive activities.” Based on this definition, drought is an internal supply-side shock. This disturbance is caused by events outside the control of the affected country. And those events have significant impacts on domestic economic sectors including agriculture. To account for the negative impact of droughts on agricultural productivity, I computed and used a 6-month SPI as a proxy for drought. The use of a drought index is a major improvement over previous studies that used a total yearly precipitation or a drought-year dummy variable as their climate change variable.\(^\text{12}\)

The SPI captures the severity of dry and wet spell. The index ranges from -4 to +4, with values of 2 or greater denoting extremely wet spells and values of 2 or less indicating extremely dry spells. The condition is said to be near normal, for SPI values between -0.99 to +0.99.

The second climatic variable used in this study is temperature. The standard approach in agricultural impact studies suggests converting daily temperature into degree - days (Grierson, 2002; Deschenes and Greenstone, 2007). A logical explanation in support to this type of approach hinges on the idea that heat accumulation is beneficial to plants only when temperature is between a base of 8 °C and a ceiling of 32 °C (Schlenker et al., 2006). I use daily data on temperature to calculate growing season degree-days from June 1 to October 31, as the region has only one growing season which coincides with the rainy season. Specifically, the variable

\(^{12}\) To capture the impacts of weather variability, past studies employed two climate variables, namely temperature and precipitation. The average annual temperature (Isik and Devadoss, 2006) or the number of growing degree days (Ritchie et al. 1991.) have been used as a proxy for change in temperature. And the variability in precipitations was captured using the average annual precipitation or cumulative annual precipitation (Pradeep and Mandelsohn, 1996).
temperature is calculated so that a day with an average temperature below 8 degrees C contributes to zero degree-days. If the average temperature is between 8 degrees C and 32 degrees C, then the contribution to the degree-days is the difference between 32 and the number of degrees above 8. Finally, for an average temperature above 32, the contribution to the degree-days is 6.2. The variable temperature is then calculated by summing the daily measures over the five months of the growing season.13

The third climate variable used is the precipitation intensity variable, calculated as the ratio of total precipitation from the month with the highest value to the yearly total precipitation. This variable captures the temporal distribution of rainfalls. Values close to one indicate that rainfalls have been poorly spread out during the year.

The data on precipitation and temperature are taken from the Africa Rainfall and Temperature Evaluation System V1.0 (ARTES), graciously given to me by Dr. Ariel Dinar, a lead economist at the World Bank. Crops and acreage variables are derived from the FAOSTAT website.

IV: Regression Analysis

Chen, McCarl and Schimmelpfennig (2004) citing Banerjee et al. (1993) point out that it may be possible for correlation to exist between time series variables even when they increase for different reasons. Therefore the correlation between the variables of interest will be spurious, which in turn will produce unreliable estimates. This spurious correlation between variables may be introduced through either deterministic or stochastic trend. To account for this possibility, I first run a panel data unit root test to the set of dependent and independent variables. The results are presented in Table 2. It appears from Table 2 that the variables are stationary as a panel, thus

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13 I use interchangeably growing season and rainy season because farmers grow millet and sorghum only during the rainy season.
rejecting the hypothesis of a panel unit root, except for maize acreage that must be first-differenced.

[Place Table 2 approximately here]

After controlling for the time trend, I run the single stage ML estimations of linear and quadratic functional forms of equation (7). But the likelihood ratio tests favor the linear estimation. The Maximum Likelihood Estimation is carried out by fitting equation (7) for maize, millet, and sorghum yields. The results are summarized in Tables 3, 4 and 5.

**Maize Yield Function**

The estimated coefficient for the degree-days variable is negative in the mean yield and positive in the variance equation, but not statistically significant in either case. These results are consistent with the hypothesis that an increase in temperature has no effect on maize production. The SPI is positively related to the mean yield and yield variability of maize and statistically significant only in the mean function. The estimated coefficient in the mean function indicates that an increase in wet spells increase the mean of maize yield. Specifically, a one unit improvement in SPI is associated with a maize yield increase of about 503 kg/ha. Gambia and Guinea Bissau are the two largest producers of maize, and they are also relatively wetter countries compared to the remaining six. Thus the relatively higher precipitation in Guinea and Gambia seems to suit the production of maize in those regions. These results are in support of Chen et al. (2004) who find that corn has a greater water requirement and grows better in more temperate area. Also, Isik and Devadoss (2006) have found similar results for Idaho.

The precipitation intensity variable has a negative coefficient and is statistically significant at 1 percent level. This result indicates that a poor temporal spread of rainfall is harmful to crop. In fact, when the tendency is a shift toward greater intensity - precipitation is recorded during only
one month (and the rest of the rainy season is dry), then the mean maize yield will decrease by 13275 kg/ha. The effects on crops of a poor rainfall spread seem to be more pronounced than the impact of drought. Of course, one may argue that a poor rainfall is also another form of agronomic drought.

The estimated coefficient for the time trend lacks a statistical significance, but also its sign differs between the mean and the variance functions. This result is somewhat startling as I expected that improved technology to increase the mean and reduce the variability of the maize yield. Probably, the time trend variable is picking up other factors besides the intended technological progress.

The positive sign of the acreage variable indicates that an increase in the cultivated area augments both the mean and the yield variability for maize. Although startling at first glance, the results with respect to acreage variable echo a report by ICRISAT (International Center for Research in the Semiarid Tropics) for noticing that maize yield has not kept up with the increase in the cultivated area that took place from the early 1970s to 2006 in Central and Western Africa. From Table 3, it appears that a 1 ha increase in acreage results in a modest 16.9 g/ha increase in crop. In other words, extending the cultivated area will not help increase maize production.

[Place Table 3 approximately here]

**Millet Yield Function**

With regards to the linear functional form, the estimated coefficients for the SPI, precipitation intensity and the time trend have a positive sign in the mean as well as the variance functions when applicable. On the other side, degree-days, acreage and time trend squared, all have a negative coefficient estimate. Furthermore, with the exception of the precipitation intensity, the estimated coefficients for the remaining variables are statistically significant. The positive sign
of the drought index and the negative coefficient on the temperature variable suggest that change in climate variables should be of great concern to the populations of Sahel. Although millet is a heat-tolerant crop, a further increase in temperature will be detrimental to the production. The difference in magnitude in the effects of temperature and precipitation on the mean of millet yield is quite noticeable. In fact, a one unit increase in degree-days reduces millet yield by 170 kg/ha, while a one unit improvement in SPI increase millet yield by 451 kg/ha. It appears that drought is more detrimental to millet yield than higher temperature.

Also, my results show that a technological improvement augments the mean and the yield variability of millet. Table 4 reveals that a technological improvement will increase millet yield by an average of 128 kg/ha. The positive sign on the trend variable is consistent with the findings by Lusigi and Colin (1997) who study 47 African countries over the period 1961-1991 and conclude that R&D expenditures play a key role in explaining the regain in productivity observed in the 1980s.

The estimated coefficient for the acreage variable is negative and statistically significant. Economically speaking, however, an increase in acreage has virtually no impact on millet yield. In fact, a 1 ha increase in acreage results in a reduction of millet yield of less than one-thousandth (0.000697).

[Place Table 4 approximately here]

**Sorghum Yield Function**

The estimated coefficients for the SPI and the time trend are statistically significant and have positive effects on the mean of the sorghum yield function. Simultaneously, the estimated equation for sorghum indicates that the degree-days, the precipitation intensity and the acreage variables tend to decrease the mean and the variance of the sorghum yield. Specifically, the
estimated coefficient for SPI indicates that a 1 unit improvement in drought index increases sorghum yield by 634 kg/ha. As for temperature, the magnitude of the effect is comparable to that of precipitation. A unit increase in degree-days reduces sorghum yield by 664 kg/ha.

Precipitation intensity appears to have the most pronounced effect on sorghum yield. When precipitation is recorded only during one month of the rainy season, sorghum yield significantly decreases by 9765 kg/ha.

With respect to the sign of the coefficients, McCarl et al. (2008) find similar results for the U.S., except that their coefficients were more often statistically insignificant.

The production of sorghum is almost equally spread throughout the region and on a global scale, Sahel is a dry area. Therefore, the results confirm my expectation that higher temperatures are harmful, while more rainfall is beneficial to sorghum. With sorghum, unlike millet, the impact of temperature and precipitation is almost identical in terms of magnitude.

The sign on the coefficient for degree-days and precipitation intensity corroborate the findings by McCarl et al. (2008) of the damaging effects of more extreme events as a result of climate change.

[Place Table 5 approximately here]

V: Conclusion

This paper has estimated the effects of a constructed index of degree-days, precipitation intensity, and a standardized precipitation index (SPI) on the mean yield and yield variability of three major crops in eight countries in the Sahelian region. I use a Just-Pope stochastic production function of maize, millet and sorghum for the period spanning from 1970 to 2000. The results suggest that the effects of climate change are similar across all crops. For the variable related to temperature, I find that an increase in the degree-days tends to be harmful to crop
yields, even though the cultivated crops are heat-tolerant. As for rainfall, expressed in terms of SPI and precipitation intensity index, my results show how it positively contributes in a statistically significant way to increase the mean of crop yields. More rainfall, evenly spread throughout the growing season, are beneficial to crops. However, the persistent occurrence of severe droughts prevents rainfall from being abundant and evenly well spread throughout the growing season. The sign of the estimates for acreage variable is crop specific however. Finally, technological improvement is consistently found to be associated with an increase in the mean yields. In sum, my results suggest that changes in temperature and precipitation are risk-increasing.

These results are robust not only to several alternative functional specifications, but to different estimation techniques as well.

The results of this study have implications in farmers’ decision to allocate agricultural land because the effects of acreage are found to be crop specific. The coefficient on the acreage variable has a positive sign in the maize yield equation, but negative in the millet yield and sorghum yield equations. In addition, there are better ways of helping rural population by giving them more access to irrigation as the bulk of rainfall is received during one month, and this paper documents that a poor rainfall spread is crop damaging.

References:


Appendix

Table 1. Descriptive statistics

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize (kg/ha)</td>
<td>248</td>
<td>9774</td>
<td>3763</td>
<td>24091</td>
<td>2500</td>
</tr>
<tr>
<td>Sorghum (kg/ha)</td>
<td>248</td>
<td>6822</td>
<td>2595</td>
<td>16419</td>
<td>1256</td>
</tr>
<tr>
<td>Millet (kg/ha)</td>
<td>248</td>
<td>6026</td>
<td>2536</td>
<td>14829</td>
<td>1076</td>
</tr>
<tr>
<td>Millet acreage (MTA)</td>
<td>248</td>
<td>861326</td>
<td>1164813</td>
<td>5366055</td>
<td>1700</td>
</tr>
<tr>
<td>Maize acreage (MZA)</td>
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<td>57117</td>
<td>71317</td>
<td>426300</td>
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</tr>
<tr>
<td>Sorghum acreage (SGA)</td>
<td>248</td>
<td>489735</td>
<td>562979</td>
<td>2530518</td>
<td>5000</td>
</tr>
<tr>
<td>Annual Precipitation (prec)</td>
<td>248</td>
<td>554.36</td>
<td>385.94</td>
<td>1755.34</td>
<td>67.08</td>
</tr>
<tr>
<td>Average Temperature (Temp)</td>
<td>248</td>
<td>26.75</td>
<td>1.41</td>
<td>29.34</td>
<td>21.33</td>
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</tbody>
</table>

Table 2. Panel Unit Root Test

<table>
<thead>
<tr>
<th>Variables</th>
<th>maize</th>
<th>millet</th>
<th>sorghum</th>
<th>MZA</th>
<th>MTA</th>
<th>SGA</th>
<th>Prec</th>
<th>Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-3.031&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-5.466&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-3.436&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.371</td>
<td>-2.645&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-1.794&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-5.403&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-4.122&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Null hypothesis of unit root is rejected with 99 percent confidence.

<sup>b</sup>Null hypothesis of unit root is rejected with 95 percent confidence.

Table 3. Impact of Temperature and Precipitation on Maize Yield in Sahel: MLE Results

<table>
<thead>
<tr>
<th></th>
<th>Mean Yield</th>
<th>Yield Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>13760 (6.779)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>2718.3 (2.363)&lt;sup&gt;**&lt;/sup&gt;</td>
</tr>
<tr>
<td>SPI</td>
<td>502.61 (1.721)&lt;sup&gt;***&lt;/sup&gt;</td>
<td>30.283 (0.151)</td>
</tr>
<tr>
<td>Intensity</td>
<td>-13275 (-3.349)&lt;sup&gt;*&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Degree-days</td>
<td>-206.98 (-0.655)</td>
<td>296.93 (1.349)</td>
</tr>
<tr>
<td>Trend</td>
<td>31.572 (0.3025)</td>
<td>-26.68 (-1.40)</td>
</tr>
<tr>
<td>Trend Squared</td>
<td>2.424 (0.802)</td>
<td></td>
</tr>
<tr>
<td>Acreage</td>
<td>0.0169 (5.343)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>-0.0163 (-8.576)&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>R-square</td>
<td>7.65 %</td>
<td></td>
</tr>
<tr>
<td>Log-likelihood Function</td>
<td>-2374.57</td>
<td></td>
</tr>
</tbody>
</table>

Notes: *, ** and *** indicate that the parameter is significant at 1%, 5% and 10% levels, respectively. The t-ratios are in parentheses.
### Table 4. Impact of Temperature and Precipitation on Millet Yield in Sahel: MLE Results

<table>
<thead>
<tr>
<th></th>
<th>Mean Yield</th>
<th>Yield Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6278.2 (8.664)*</td>
<td>2718.3 (2.363)**</td>
</tr>
<tr>
<td>SPI</td>
<td>451.06 (5.676)*</td>
<td>117.75 (2.119)**</td>
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<tr>
<td>Intensity</td>
<td>239.21 (0.173)</td>
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<tr>
<td>Degree-days</td>
<td>-170.51 (-1.924)***</td>
<td>-98.249 (-2.083)**</td>
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<tr>
<td>Trend</td>
<td>128.06 (3.919)*</td>
<td>36.582 (4.14)*</td>
</tr>
<tr>
<td>Trend Squared</td>
<td>-2.467 (-2.802)*</td>
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</tr>
<tr>
<td>Acreage</td>
<td>-0.000697 (-13.09)*</td>
<td>-0.000572 (-15.87)*</td>
</tr>
<tr>
<td>R-square</td>
<td></td>
<td>13.65 %</td>
</tr>
<tr>
<td>Log-likelihood Function</td>
<td></td>
<td>-2228.9</td>
</tr>
</tbody>
</table>

Notes: *, ** and *** indicate that the parameter is significant at 1%, 5% and 10% levels, respectively. The t-ratios are in parentheses.

### Table 5. Impact of Temperature and Precipitation on Sorghum Yield in Sahel: MLE Results

<table>
<thead>
<tr>
<th></th>
<th>Mean Yield</th>
<th>Yield Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>13175 (12.75)*</td>
<td>2718.3 (2.363)**</td>
</tr>
<tr>
<td>SPI</td>
<td>634.17 (4.04)*</td>
<td>114.90 (1.057)</td>
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<tr>
<td>Intensity</td>
<td>-9765.1 (-4.688)*</td>
<td></td>
</tr>
<tr>
<td>Degree-days</td>
<td>-664.31 (-3.957)*</td>
<td>-382.27 (-3.318)*</td>
</tr>
<tr>
<td>Trend</td>
<td>161.13 (2.929)*</td>
<td>-4.2013 (-0.394)</td>
</tr>
<tr>
<td>Trend Squared</td>
<td>-3.0937 (-1.87)***</td>
<td></td>
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<tr>
<td>Acreage</td>
<td>-0.00287(-18.81)*</td>
<td>-0.000633 (-6.056)*</td>
</tr>
<tr>
<td>R-square</td>
<td></td>
<td>38.31 %</td>
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<tr>
<td>Log-likelihood Function</td>
<td></td>
<td>-2229.09</td>
</tr>
</tbody>
</table>

Notes: *, ** and *** indicate that the parameter is significant at 1%, 5% and 10% levels, respectively. The t-ratios are in parentheses.
2. **Figure:**

![Figure 1. Average Crop yield by year in Sahel.](image-url)