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Abstract

This paper analyses the economic effects of temperature and rainfall variability on the net income of the main cereal crops in Togo based on a semi-parametric specification of the Ricardian model. The model provides a flexible functional form of the non-linear relationship between farmers' net income and climatic variables and evaluates the effect of climate variability on the net income of these crops. Using data from the National Agricultural Census in Togo, temperature and rainfall data from spatial interpolation over all prefectures and soil type data for each locality, the results of the semi-parametric estimates reveal a complex non-linear relationship of temperature and rainfall variability on the net income of crops. In addition, a combination of crops and agro-forestry practices reduce the effects of climate variability on net income from cereal crops. Furthermore, variations in temperature and rainfall under socio-economic scenarios result in lower net income from cereal crops. The projections show that long-term variability in temperature and rainfall will have a negative impact on net income and that the impact will be greater in 2050 for all crops.

Keywords: Net income, Climatic variability, Semi-parametric approach, Cereals

1.0 Background and Justification

Globally, and particularly in most developing countries, the agricultural sector is the lung of the national economy, contributing a significant share to the formation of Gross Domestic Product (Bryan et al., 2011). It also provides the basis for feeding all humankind by ensuring its social well-being and prosperity. However, the growth of the world population in recent years and its projection reveal that food production should increase by 60% to 70% by 2050 to guarantee food security for its inhabitants (Tilman et al., 2011; FAO, 2009, Bruinsma, 2009). However, agricultural production, mainly dependent on rainfall, in most developing countries and particularly in Togo, remains sensitive and vulnerable to the climatic parameters variability witnessed over the past decades (Mendelsohn, 2000; IPCC, 2007; Kurukulasuriya and Mendelsohn, 2006).

In this context, observation of the climate system in Togo on the basis of direct measurements of climatic variables conducted by the national meteorological services during the period from 1961 to 2012 reveals a global warming trend of 1°C for the period from 1961 to 2012, coupled with a decrease in average rainfall throughout the country. This global warming became more pronounced during the years 1986 to 2012 compared to the normal level from 1961 to 1985, with annual deviations of between 0.7°C and 1.2°C, respectively. Considering the 1961-1985 baseline period, the years 1986 to 2012 show a deficit in terms of rainfall, with reductions in rainfall between 3mm and 81mm. The evolution of rainfall patterns reveals an alteration in rainfall distribution with, among the major climatic risks, situations of extreme droughts or paradoxically floods and a decrease in the number of rainy days.

As agriculture in Togo is essentially dependent on rainfall, this climate variability is likely to influence crop yields and reduce farmers' income. In this context, several studies have attempted to analyze the impact of climate variability on agricultural production in several countries around the world and at the regional level (Dall'erba and Domínguez, 2016; Kabubo-Mariara and Karanja, 2006; Kurukulasuriya and Mendelsohn, 2007; Mendelsohn and Dinar, 2003; Mendelsohn et al., 1994), but few studies on Togo, following the example of Gadédjisso-Tossou et al. (2016) and Pilo and Adeve (2016). Thus, the literature abounds with several approaches and tools used to analyze the potential effects of climate parameters variability on agriculture (Mendelsohn and Dinar, 2009). However, among the pioneering works, Adams et al. (1990) and Kaufmann and Snell (1997) used biophysical crop models to simulate the impact of climate variability on plant growth and input requirements.

In addition, assessment of the impact of climate parameter variability has focused on crop productivity (Schlenker and Roberts, 2009; Welch et al., 2010) or agricultural profit (Deschênes and Greenstone, 2012) by making greater use of statistical or econometric models with time series, cross-sectional or panel data. However, these different methods do not integrate farmers' adaptation strategies in response to climate variability, which may lead to biases in the estimates. To take into account the limitations of these previous approaches, Mendelshon et al. (1994) introduced the Ricardian approach in the economic literature. This approach is based on the notion of a competitive market in which the value of agricultural land reflects the present value of all the expected future benefits that can be derived from it (Ricardo, 1817). The Ricardian model specification is generally implemented by regressing agricultural land values on climatic variables, mainly temperature and rainfall, and a set of exogenous control variables. The main advantage of this approach is that it integrates farmers' adaptation strategies. There are, however, some criticisms associated with it, notably those relating to the implicit fixed price assumption and the functional form of its specification.

Indeed, Ricardian analysis generally assumes that the impact of climate variability will affect the value of agricultural land in a non-linear manner (Mendelsohn and Dinar, 2009). Thus, model specification integrates the quadratic terms of the climate variables to show this non-linear relationship between climate and agricultural land value. Moreover, previous research has shown that in hedonic models, the restrictive parametric specification to the quadratic form of the climate variables cannot be justified a priori (Cropper et al., 1987 and Ekeland et al., 2002; 2004). However, an alternative semi-parametric or non-parametric method can provide several advantages over this limitation of the specification of the functional form of the standard Ricardian model (Anglin and Gencay, 1996; Parmeter et al., 2007; Bontemps et al., 2008). In comparison to parametric regression, the semi-parametric method provides a superior fit and reveals a strong interaction between climate variables. Furthermore, predictions of the impact of climate variability are not significantly different from those obtained using the standard specification.

1.1 Objectives

The general objective of this paper is to analyze the effects of temperature and rainfall variability on the net income of the main cereal crops in Togo using a semi-parametric approach of the Ricardian model.

Specifically, the paper will:

(i.) Analyze the impact of temperature and rainfall variability on the net income of the main cereal crops in Togo.

(ii.) Estimate, based on different IPCC scenarios, the effect of climate variable projections on the net income of cereal crops in the years 2025 and 2050.

1.2 Assumptions

In this study, we make two assumptions as anticipated responses:

(i.) Temperature and rainfall variability negatively affect the net income of the main cereal crops in Togo.

(ii.) The scenario of rising temperatures and decreasing rainfall will be detrimental to cereal production in the years 2025 and 2050.

In the light of the pursued objectives, this paper makes three main contributions to the literature. First, it uses a semi-parametric specification of the Ricardian model to estimate a flexible functional form of the relationship between climate and agriculture and to reduce the bias associated with the specification of the functional form of the standard Ricardian model. Then, this paper helps to fill the gap in the literature with respect to research works investigating the impact of climate parameter variability on agriculture in Togo. Finally, since most of the work focuses on agricultural production in general, this research work analyses, at farm level, the interaction effect of temperature and rainfall variability on the net income of cereal crops.

2.0 Literature Review

The economic analysis of the potential effects of climate variability on farmers' incomes has been the subject of several studies in the literature. Since the variability of climate parameters is one of the main causes of variation in production levels and crop productivity, it also influences farmers' incomes and that of countries through the contribution of the agricultural sector to GDP. However, this section presents some empirical studies and elements of methodological analysis on the work carried out in the literature.

2.1 Empirical Evidence

Climate variability, agriculture and food security are currently at the centre of issues that concern countries around the world. This is evident from the amount of empirical work available on this topic. However, authors such as Adams et al. (1988; 1989; 1990; 1998), and Rosensweig and Parry (1994), Mendelssohn et al. (1994), Onyeji and Fischer (1994), Gbetibouo and Hassan (2005); Sands and Edmonds (2005) were the pioneers in analyzing the impact of climate variables on agricultural production in different countries of the world. The production function approach, which links climatic variables and agricultural production variables was the subject of the first research work on this issue. In this context, the research by Rosenzweig and Parry (1994), based on this approach, contributed to the global assessment of the potential impact of climate change on the world food supply. The results suggested that a doubling of carbon dioxide concentration in the atmosphere would lead to a decrease in global agricultural production, but the authors show that developing countries are likely to bear the brunt of the problem. To overcome the various limitations of this approach, Chang (2002) combines the production function approach with an optimization model to estimate the effect of temperature and rainfall variations on the value of agricultural production in the long term. These results reveal that variation in climate parameters will have a negative effect on agricultural production and, in particular, his findings show that increased rainfall will have devastating effects on agricultural production.

The development of tools for analyzing the effects of climate on the agricultural sector has enabled Mendelssohn et al. (1994) to estimate the impact of agro-climatic factors on the value of land in the USA for almost 3,000 agricultural sites using the Ricardian model. Their results showed that high temperatures in all seasons except autumn reduce farmers' average values, while high rainfall outside the autumn season increases land values. In addition, they showed that global warming could have economic benefits for agriculture at the county level in the USA. In addition, Dall'erba and Domínguez (2016) evaluate the effect of variation in climate parameters on county agricultural land values in the semi-arid southwestern United States using the Ricardian model. Compared to previous studies, their study focused on a single climatic zone. The results show that the probability of realizing losses is high for farmers in the high-altitude counties, while gains and losses are relatively equally possible for farmers in the low-altitude counties, where climate has less influence on land values.

In Africa, although the studies carried out on this subject seem insufficient, Gbetibouo and Hassan (2005) in South Africa, Eid et al. (2006) in Egypt, and Kurukulasuriya and Mendelsohn (2007) used the Ricardian approach to assess the economic impact of the variation of climatic parameters on crops throughout Africa. These authors used a regression of net agricultural income on climatic variables, soil and other socio-economic factors, considering farmers' responses to variations on climatic variables. In general, the results suggest that crop production in the basins was sensitive to a slight variation in temperature compared to variations in rainfall. The increase in temperature had a positive effect on net income while the effect of reduced rainfall was negative.

2.2 Elements of Methodological Analysis

There are several approaches in the literature for estimating the economic impact of climate variability on farmers' incomes. The two traditional approaches used in economics are the Ricardian approach, which is the most widely used, and second, the production function approach, which is based on integrated assessments of combinations of crop productivity model outputs and economic models.

(a.) Production Function Approach

The production function approach pioneered by Adams et al. (1988; 1989; 1990; 1998), and Rosensweig and Parry (1994) is an experimental approach that attempts to measure the direct effects of climate change on different crops and their input requirements (light, pesticides, herbicides, fertilizers, etc) using biophysical plant simulation models. The advantage of this approach is that it allows precise measurement of the response mechanism of crops to climate by observing their behaviour individually and controlling all other variables that may influence plant growth (Adams et al., 1988; Nefzi, 2012). The production function approach has nevertheless undergone significant improvements over the years to address its main shortcoming of not taking into account possible adaptation strategies that farmers can implement. However, from the point of view of its experimental design, it will never be able to take into account the full range of potential adjustments and responses to hypotheses about farmers' possible behaviour in the face of climate change, rather than observing their actual behaviour in the farm (Segerson and Dixon, 1999).

(b.) Ricardian Approach

Mendelssohn et al. (1994) provided a solution to the major shortcoming of the production function approach by introducing the Ricardian approach (Seo and Mendelssohn, 2008a). This approach attempts to directly measure the effect of climate on land values and crop yields using cross-sectional data. It has been used in the literature by several authors to estimate the economic impact of the variation of climate variables on agriculture (Deressa and Hassan, 2009; Kumar and Parikh, 1998; Sanghi et al., 1998; Schlenker et al., 2006; Eid et al., 2006; Molua and Lambi, 2006; Kabubo-Mariara and Karanja, 2006; Sene et al., 2006; Kurukulasuriya and Mendelssohn, 2006 and Mano and Nhemachena, 2006) by implicitly analyzing farmers' behaviour and taking into account their level of adaptation. To this effect, the Ricardian approach makes it possible to explain the discounted value of land or net profit that reflects the costs and benefits associated with agricultural practices and adaptation measures in the presence of climate parameter variations (Mendelssohn et al., 1994).

Despite some strength, this method has some limitations. Cross-sectional analysis using the Ricardian method does not take into account the dynamic transition costs that can occur when farmers move between two States. Critics also point out that the theoretical assumption of long-term factor price equilibrium is not always true in developing countries where markets are not integrated (Cline, 1996). Recently, there has been a debate on the specification of the functional form of the standard Ricardian model, which integrates the quadratic terms of the climate variables resulting in a rigid non-linear relationship between climate variables and land values.

Building on previous work, this research helps to shed light on the relationship and potential economic effects of variability in climate parameters, particularly temperature and rainfall, on grain production. However, we adopt in this paper the Ricardian approach, used in several works in the world and in African countries, given that it integrates the different adaptation strategies implemented by farmers in response to perceived variability in climate variables (Kurukulasuriya and Mendelsohn, 2007; Maddison et al., 2007; Mendelsohn and Seo, 2007; Strzepek and McCluskey, 2007; Seo and Mendelsohn, 2008b; Van Passel et al., 2012). However, to reduce the bias that may be caused by the limitations of the Ricardian model, we use a semi-parametric specification of this model developed by Li and Racine (2007). This specification offers the advantage of testing the validity of the non-linear relationship between climate variables and agricultural land values following a flexible functional form of the Ricardian model using non-parametric statistical tests (Hastie and Tibshirani, 1993).

3.0 Methodology

The Ricardian approach (Mendelsohn et al., 1994) examines how agricultural land values vary according to a set of exogenous variables such as climate and soils. It is based on David Ricardo's (1772-1823) observation that in a competitive market, land income would reflect net agricultural land income (Ricardo, 1817) and analyzes the impact of climate and other variables on land values or farming incomes. This approach is attractive because it corrects for biases in the production function approach by directly measuring the effects of climate on the value of production of different crops, and the indirect substitution of different inputs and the introduction of potential adaptation strategies by farmers as responses to the negative effects of climate (Mendelsohn et al., 1994).

The Ricardian approach is based on a set of well-formed production functions:

$$Q_i = Q_i(K_j, E) \qquad i = 1, \dots, n \tag{1}$$

Where, Q_i is the quantity of good i produced, K_j is an input vector j used to produce Q_i and E defines the vector of exogenous environmental factors such as temperature, rainfall and soil characterizing the production sites.

Considering the price vectors of the production factors wj, the climatic variables E and the total quantity produced Q, minimization of production costs gives the following production cost function:

$$C_i = C_i(Q_i, W, E) \tag{2}$$

Where C_i is the cost of production for the good i and W (w_1, w_2, ..., w_n) is the factor price vector. Using the cost function C_i at market prices, the profit maximization of a farmer on an agricultural site can be specified as follows:

$$\max_{Q_i} \pi = [P_i Q_i - C_i(Q_i, \omega, E) - P_L L_i] \tag{3}$$

Where, L_i represents the land on the farming site and P_L is the annual cost or lease for farming on that site, such that under ideal competition, all profits above the normal returns from all factors (land rents) tend towards zero.

$$P_i Q_i - C_i(Q_i, \omega, E) - P_L L_i = 0 \qquad (4)$$

If the production of the good i is a result of the best use of the cultivated parcel of land, given E, the market rent of the parcel would be equal to the annual net profit from the production of the good. Solving the above equation allows for equality between the rent per hectare from the farm to the net income per hectare.

$$P_L = [P_i Q_i - C_i(Q_i, \omega, E)]/L_i \qquad (5)$$

The present value of the agricultural activity's current and future income flows gives the value VL such as:

$$V_L = \int_0^\infty P_L e^{-rt}\, dt = \int_0^\infty \left[\left(P_i Q_i - C_i(Q_i, \omega, E)\right)/L_i\right] e^{-rt}\, dt \qquad (6)$$

Equation (6) therefore measures the impact of climatic variables on current land values while examining the relationship between these climatic variables and land values. The reduced form of equation (6) can be presented as:

$$V_L = f(X, Z, G). \qquad (7)$$

Where V_L represents the land value per hectare, *X* the climatic variables, Z the soil variables (soil types), *G* the socio-economic characteristics of the farmers and *f* (.) represents *a priori* the unknown functional form between the land value and the exogenous variables, especially the climatic variables *(X)*. However, in most hedonic models, economic theory provides little guidance on the form of this relationship.

The available literature reveals that there is a concave or convex relationship between agricultural value and climate variables. The Ricardian approach thus integrates the quadratic terms of the climate variables to obtain this relationship by taking into account the effect of other farmer-specific variables in the estimation of the impact of climate variability on the value of agricultural land (Kurukulasuriya et al., 2004; Dall'erba and Domínguez, 2016; Kurukulasuriya and Mendelsohn, 2007). This is the limitation of this approach in that it restricts impact to very specific functional forms. That is, in such a model, climate impacts are forced to be quadratic and their interaction is assumed to be linear. While these approaches may be reasonable, there is no theoretical justification underlying the rigidity of such a structure, which was mainly adopted by Mendelshon et al. (1994) to facilitate estimation. Therefore, it is interesting to study a flexible functional form of the Ricardian model without a quadratic specification of the climate variables (Fezzi and Bateman, 2012) following a semi-parametric function in the form of:

$$V_{L_i} = f(X_i) + \beta Z_i + \varepsilon_i \qquad (8)$$

Where V_{L_i} represents the logarithm of the value of agricultural land, X_i the vector of climatic variables composed of temperature and rainfall, Z_i the vector of soil, socio-economic and socio-demographic variables, β the vector of parameters to be estimated and ε_i the error term. The functional form of f (.) is not specified and constitutes the non-parametric part of the model. The climate variables X_i in the model affect the explanatory variable in a flexible manner without taking any functional form. Following Yatchew (2003) and Li and Racine (2007), this approach makes it possible to simultaneously deal with the non-linearity in the relationships and to estimate the effects of climate variation on the value of agricultural land. Robinson's (1988) estimation method based on a two-step procedure allows us to estimate this model.

In the first part, we will estimate the coefficients of the parametric part by eliminating the unknown function ff(.) in equation (8).

To do so, let us determine the conditional expectation of equation (8) with respect to $X_i X_i$. The result is thus:

$$E(y_i/X_i) = f(X_i) + E(Z_i/X_i)'\beta + E(\varepsilon_i/X_i) \qquad (9)$$

By subtracting this equation (equation 9) from equation 2 and assuming that $E(\varepsilon_i/X_i) = 0$ because climate variables should not be correlated with the error term, we have:

$$y_i - E(y_i/X_i) = E[Z_i - E(Z_i/X_i)]'\beta + \varepsilon_i \qquad (10)$$

We put: $\tilde{y}_i = y_i - \hat{E}(y_i/X_i),\ et\ \tilde{Z}_i = [Z_i - E(Z_i/X_i)']$

Equation 4 can be converted to a linear equation as follows:

$$\tilde{y}_i = \beta \tilde{Z}_i + \varepsilon_i \qquad (11)$$

We can therefore estimate β from the Ordinary Least Squares method, and the vector $\hat{\beta}$of the estimated coefficients would be:

$$\hat{\beta} = [\textstyle\sum_{i=1}^{n} \tilde{Z}_i \tilde{Z}_i']^{-1} \sum_{i=1}^{n} \tilde{Z}_i \tilde{y}_i \qquad (12)$$

$\hat{\beta}$ depends on $E(y_i/X_i)$ and $E(Z_i/X_i)$ and can therefore be estimated using a non-parametric regression method, Kernel density regression (Li, Q.; Racine; 2007).
In the second step, the function $f(.)$ was estimated from $\hat{\beta}$ following the relation:

$$y_i - \hat{\beta}\tilde{Z}_i = f(X_i) + \varepsilon_i \qquad (13)$$

By considering that $y_i - \hat{\beta}\tilde{Z}_i = \bar{y}_i$ we will have a non-parametric form of equation (13) which can be rewritten as follows:

$$\bar{y}_i = f(X_i) + \varepsilon_i \qquad (14)$$

According to Li et al. (2002) and Li and Root (2010), the kernel estimator allows us to estimate locally the Kernel density by minimizing $\sum_{i=1}^{n}[\bar{y}_i = f(X_i) + \varepsilon_i]^2 K\left(\frac{X_i - x}{h}\right)$, with $K(.)$ as the Kernel density function.

This specification takes into account the climate variability that would impact the value of agricultural production.

The semi-parametric model has the advantage of permitting more flexibility in functional forms than a linear parametric model (Ahmad et al., 2005). The specification of this model also avoids many of the data dimension problems in strictly parametric models.

One of the most significant challenges affecting the use of the Ricardian approach is the availability of data, particularly with respect to developing countries. Indeed, the absence of a well-functioning land market in the context of developing countries makes it impossible to have information on the value of agricultural land (Kumar and Parikh, 1998). Thus, to extend the application of this model in these countries for which data on land values are not available, some authors have proposed the use of data from surveys in different climatic zones (Lippert et al., 2009; Mendelsohn et al., 2010). These data provide more detailed information on farms and agricultural activities, thereby making it possible to consider net income rather than the value of agricultural land as the dependent variable. Moreover, according to Mendelsohn and Dinar (2003), net income reflects short-term climate variations, while land value reflects a long-term scenario. Additionally, net income is a robust measure of land value because it does not depend on assumptions of discount rates on future income (Kurukulasuriya and Ajwad, 2007).

However, the use of agricultural cross-sectional data and net farm income as the dependent variable allows for the inclusion in the analysis of control variables such as proxies for farmers' adaptation strategies to measure the effects of climate variability on farm profits. Since one of the advantages of the Ricardian approach is that it takes into account farmers' different adaptation measures, the literature shows that farmers have a perception of climate variability and, in response, adopt strategies to reduce the effects on their production. To this end, the current strategies adopted by farmers pertain to irrigation (in terms of duration, quantity or frequency), modification of planting dates, use of selected seeds adapted to heat waves, and crop combinations. These different strategies will be used in this paper to measure their impacts on farmers' net income. According to Kelly et al. (2005), in the absence of adaptation strategies, agricultural production will suffer a greater reduction due to the warmer climate, and a full use of adaptation strategies can reduce the loss of value in production. Considering the example of irrigation, in the event of a rainfall deficit, the use of this strategy can help to ensure crop growth and thus reduce the effects on farmer's income (Kurukulasuriya and Mendelsohn, 2007).

3.1 Empirical Specification

Following Egbendéwé et al. (2011) and Fezzi and Bateman (2012), we consider two forms of the non-linear specification of the function $f(.)$ of equation (8). The first assumes a function comprising the unknown form of $f(.)$ with respect to the climate variables and the second assumes an aggregate form of the climate variables. In the first specification, $f(.)$ is a smoothing function of the variability of temperature and rainfall measured by the mean of their annual standard deviations. Thus, the empirical relationship between the net income per hectare of different cereal crops, climatic variables, soil types and socio-economic variables can be written as follows:

$$\log(rev\_n_{ik}) = f(STDtemp_{il}, STDprecp_{il},) + \beta' Z + \delta' G + \varepsilon_i \qquad (15)$$

Where rev_n_{ik} est is the net income per hectare of farmer *i* for all cereals or cereal *k* = maize, millet, sorghum and paddy rice; $STDtemp_{il}$, are, respectively, the standard deviation of the average temperature and rainfall experienced by farmer *i* in locality *l* ; Z and G represent, respectively, the set of soils and socio-economic variables. .δ' is the vector of the linear coefficients of the socio-economic control variables, and β' is the vector of the coefficients of the soil types. In this specification, climate variables are measured by the standard deviation of rainfall and temperature.

In the second specification, where we assume an aggregate effect of climate variables, the empirical formulation of the model can be written as follows:

$$\log(rev\_n_{ik}) = f(STDtemp_{il}) + f(STDprecp_{il}) + \beta' Z + \delta' G + \varepsilon_i \qquad (16)$$

Where $STDtemp_{il}$, $STDprecp_{il}$ are, respectively, the standard deviation of the mean temperature and rainfall experienced by farmer *i* in locality *l* ; Z and G represent, respectively, the set of soils and socio-economic variables.

The first specification is the most appealing in such an empirical analysis because it takes into account all possible functional forms of the effects of climate variables on the net income per hectare of cereal crops.

3.2 Forecasting Climate Impacts

To analyze the future effects of climate variability on farmers' net income, we use the regressions estimated in the previous section to investigate how scenarios on the variability of climate parameters could affect these net incomes. These projections use the cross-sectional estimation results for the long-term time series analysis and assume that all other variables remain constant.

The simulations are based on a set of climate change scenarios projected by the IPCC (2013), in particular the RCP8.5 scenarios, which predict how the climate will change in the medium term (2025) and long term (2050) for each country in Africa.

3.3 Data and Sources

The agricultural data used in this research are from the National Agricultural Census conducted among agricultural households across the country. This census was conducted according to the modular approach of the FAO 2010 World Programme for the Census of Agriculture (basic and community modules using comprehensive census and additional sampling modules), which allows for the articulation of the agricultural census in an integrated agricultural census and survey system with a community component. The sample on which this survey was conducted covers 508,599 agricultural households throughout Togo, although households engaged only in agriculture account for 14% of the households surveyed. However, the processing of data according to the availability of information from the farmers surveyed in relation to the three main cereal crops allows us to consider in our estimates 4,665 maize producers, 1,704 sorghum producers and 999 paddy rice producers.

Monthly rainfall and temperature data were collected at all weather stations across the country. We then used the spatial interpolation method of Thin Plate Spline (Wahba; 1990 and Hong et al., 2005) to generate rainfall and temperature for the different localities using information on the latitude and longitude of each locality. It should be noted that any spatial interpolation is subject to uncertainty associated with the choice of interpolation method, measurement errors, and variability in altitudes, slope and other spatial factors. Given the limitations of spatial interpolation of climate data, the best method to improve the quality of spatial rainfall estimation is to increase the density of the monitoring network and test the validity of the interpolation by performing a counter interpolation (Hutchinson, 1998). Like many other developing countries, we have few weather stations. Thus, to minimize uncertainties, we used several data points to interpolate climate data. We used QGIS software to perform the interpolation. Similar procedures have been adopted in the literature by Mckenney et al. (2000) and in many other similar studies.

In the entire country, we identify several cereal crops with specific focus on the three (3) main crops (maize, paddy rice, sorghum) which will be considered in our analysis as they cover almost 90% of the cultivated land with cereals. Soil data came from the Food and Agriculture Organization (FAO, 2003). These data provide information on most of the soils in each locality. Table 1 provides a description of all the data.

Table 1: Overview of descriptive variable statistics

Variable	Description of variables	Mean	Std. Dev.
Dependent variables			
Net income - rice	Net income from paddy rice production	423,179	1,076,239
Net income - sorghum	Net income from sorghum production	120,688	432,083
Net income - maize	Net income from maize production	102,832	288,479
Net income -cereals	Net income from production of all types of cereals	164,210	559,600
Climate variables			
Temperature	Average temperature during the rainy season (in °C)	27.49	0.54
Rainfall	Average rainfall during the rainy season (in mm)	135.23	22.08
Temperature deviation	Standard deviation of temperatures in the rainy season (in °C)	0.01	0.54
Rainfall deviation	Standard deviation of rainfall in the rainy season (in mm)	0.13	22.08
Socio-economic variables			
Age	Age of the farmer (in years)	30	17.37
Gender	Gender of the farmer (0. Female 1. Male)	0.52	0.50
Size	The size of the farmer's household	3.51	2.09
Level of education	Level of education of the farmer (0. no level; 1. primary; 2. secondary and higher)	0.88	0.78
Farm surface area	The total area under cultivation by the farmer (in ha)	32.58	122.10
Grain/cereal price	Selling price of cereal products (in FCFA per Kg)	173.68	31.25
Use of irrigation	Irrigation practice by the farmer (0. No 1. Yes)	0.01	0.12
Agro-forestry practice	Practice of agro-forestry by the farmer (0. No 1. Yes)	0.12	0.32
Crop combination	Combination of crops by the farmer (0. No 1. Yes)	0.57	0.50
Type of seed	Type of seed used by the farmer (0. Traditional 1. Selected)	0.11	0.31
Latitude	The latitude of the location of the farm (decimal degree)	8.25	1.66
Membership to an organization	Membership of the farmer in a socio-economic group (0. No 1. Yes)	0.10	0.30
Semi date	Semi-cropping date (number of days compared to the beginning of the year)	190.97	84.39
Access to credit	Access to credit by the farmer (0. No 1. Yes)	0.04	0.20
Livestock management	Management of livestock by the farmer (0. No 1. Yes)	0.31	0.46
Soil variables			
Luvisolian soil	Soil type Luvisols prevailing on the farm (0. No 1. Yes)	0.72	0.45
Nitrosols soil	Soil type Nitrosols prevailing on the farm (0. No 1. Yes)	0.01	0.09
Lithosol soil	Lithosol soil type prevailing on the farm (0. No 1. Yes)	0.20	0.40
Nithosol soils	Soil type Nithosols prevailing on the farm and considered as soil reference variable (0. No 1. Yes)	0.08	0.27

Source: Using data from the National Agricultural Census (2013) and the National Meteorological Office

3.4 Estimation Procedures

We first estimate the standard Ricardian and semi-parametric model for all cereal crops, with the aim of analyzing the economic effects of climate variability on the cereal production of farmers in Togo. The specification of the Ricardian standard model in the Togolese context takes into account the linear and quadratic terms of the climatic variables (standard deviation of temperature and rainfall) to analyze the non-linear relationship existing between the net agricultural income of cereal crops and the climatic variables. This specification is in line with the standard Ricardian model applied in various research works in the literature (Mendelsohn et al., 1994; Mendelsohn and Nordhaus, 1996; Kumar and Parikh, 1998; Sanghi, 1998; Sanghi et al., 1998; and Mendelsohn and Dinar, 1999; 2003).

Indeed, the positive sign of the quadratic terms' coefficient reveals a U-shaped relationship of the net income function, while a negative sign indicates an inverted U-shaped relationship of the agricultural net income function (Mendelsohn and Dinar, 2003). Referring to the various empirical works using the production function approach or the Ricardian cross-section approach, we expect an inverted U-shaped relationship between temperature and net income from the production of the main cereal crops. Furthermore, the estimation assumes a linear relationship between the net income from cereal crops and the other variables (soil, socio-economic) in accordance with the above-mentioned studies using the Ricardian approach.

Econometric analysis of the cross-sectional data is generally associated with problems of heteroskedasticity, multicollinearity and outliers in the variables (Benhin, 2006). Since these econometric problems are likely to affect the robustness of the regression results, some testing has been done and solutions have been undertaken to correct for these problems. White's heteroskedasticity test was performed to check the heteroskedasticity of the error terms followed by a correlation analysis to examine the possibility of association of the independent variables and to check their multicolinearity. In addition, the Variance Inflation Factor (VIF) was used for the same purpose. During this estimation process, some variables and observations were dropped because of their high collinearity. To correct for heteroskedasticity, a robust regression was estimated instead of a simple ordinary regression.

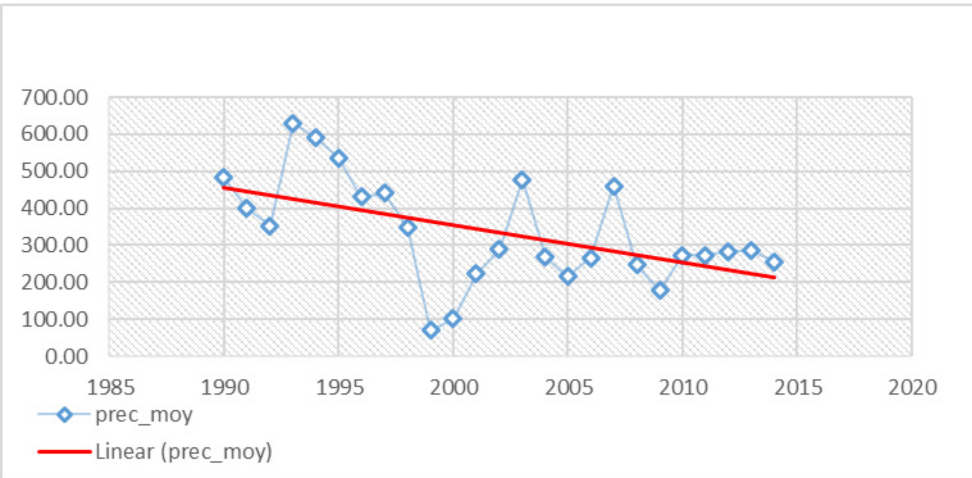
4.0 Analysis of Results

This section highlights, in the first part, the descriptive analyses of the main variables and then presents and discusses the results of different econometric estimates.

4.1 Descriptive Analysis

Analysis of the evolution in average annual rainfall in Togo over the period 1990 to 2014 reveals a decreasing trend in annual rainfall amounts in all economic regions of the country. This downward trend in rainfall can be explained by the reduction in the quantity of rainfall or a reduction in the number of rainy days observed in different regions of the country.

Figure 1: Evolution of the mean annual rainfall between 1980 and 2014



Source: Using data from the National Directorate of Meteorology

In addition, there is an uneven distribution of rainfall levels in the different regions of the country. To this end, the Central and Plateau regions record the highest levels of rainfall compared to the other economic regions. The Savannah region has the least amount of rainfall with an average rainfall of 1,039.91mm.

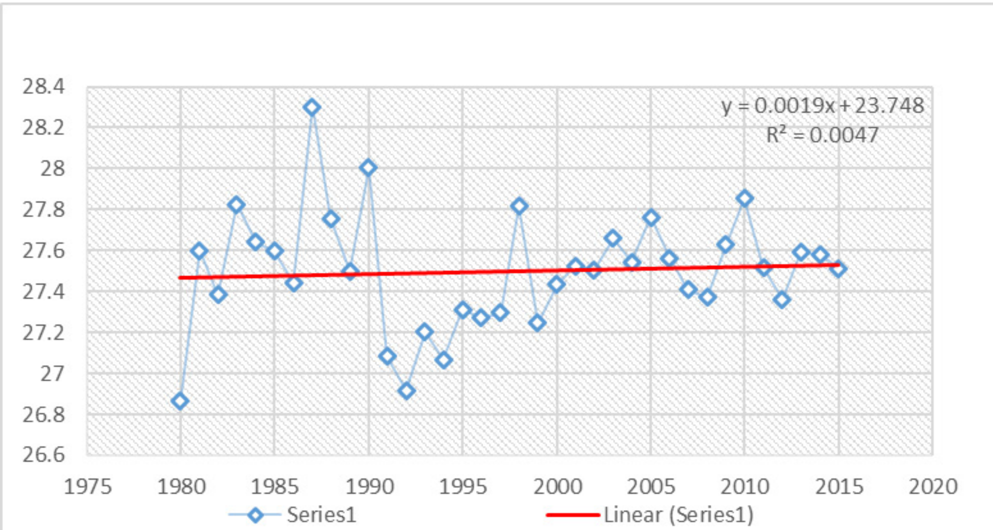
Table 2: Distribution of total rainfall by regions

Regions	Rainfall		
	Average	Min.	Max.
Maritime	1,122.26	1,056	1,244
Highlands	1,216.45	1,056	1,320
Central	1,241.52	1,122	1,320
Kara	1,203.47	1,086	1,270
Savannah	1,039.91	942	1,178

Source: Based on data from the National Directorate of Meteorology

Analysis showing the evolution of annual temperatures over the period 1980 to 2015 reveals that, on average, the temperatures are between 26.86°C and 28.30°C. In addition, the average temperature trend curve has an increasing slope revealing an upward trend in the average annual temperature in Togo.

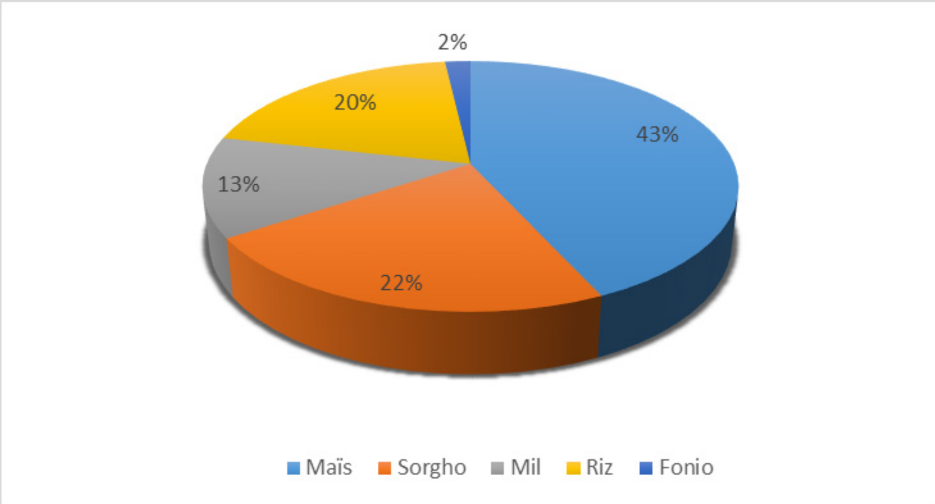
Figure 2 : Evolution of average annual temperatures



Source: Based on data from the National Directorate of Meteorology

Moreover, agricultural production in Togo is particularly concentrated on food crops, where the bulk of production is cereals. Over the period from 2000 to 2014, the cereal crops produced are generally made up of maize, paddy rice, millet, sorghum and fonio. The distribution of average production during the 2000 to 2014 agricultural campaigns reveals that maize is the most cultivated crop, accounting for about 43% of all cereal crops. Fonio crop production is relatively very low, accounting for about 2% of total cereal production.

Figure 3: Distribution of main cereal commodities



Source: Data from Agricultural Statistics, Information, and Documentation Directorate DSID

The distribution of farmers' cereal production by region in Table 3 reveals that, on average, individual maize production is higher in the Central Region (1,039.6 kg) and the Plateau (838.7 kg). Rice and sorghum are grown more in the Maritime and Plateau regions compared to the other regions.

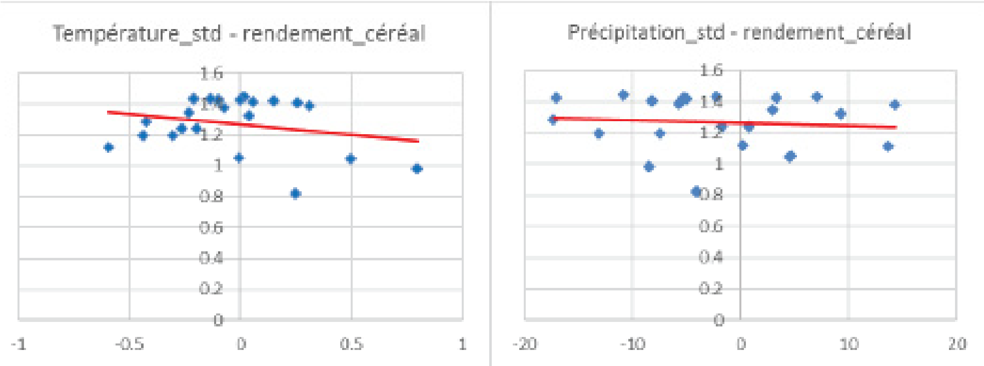
Table 3 : Distribution of average cereal production per farmer (in kg)

Regions	Maize	Sorghum	Rice
Maritime	452.76	-	21,318.79
Plateaus	838.73	2,044.34	11,194.38
Central	1,039.59	873.92	
Kara	271.76	552.90	126.48
Savannah	574.85	438.71	218.29

Source: Data from DSID

Analysis of the correlation between the yield of all grain crops and the standard deviation variables of temperature and rainfall (Figure 4) over the period 1984 to 2014 reveals a declining trend in grain crop yields. However, these trends highlight the impact of climate on cereal production in Togo, which will be verified by empirical analyses in the following section.

Figure 4: Correlation between cereal crops productivity and standard deviation of climatic variables



Source: Based on data from the National Directorate of Meteorology

4.2 Econometric Estimation Results

4.2.1 Effect of climate variability on net income per cereal crops

Table 4 presents the results of the estimates of the standard Ricardian model and those of the semi-parametric estimate in relation to all cereals. The net income per hectare for all cereals is estimated on the variability of climatic variables (measured by their standard deviation), soil variables and the socio-economic variables of farmers.

Analysis of Table 4 results using the Fisher-Snedecor test shows an overall significance of the standard Ricardian and semi-parametric models at a level of 1%. Moreover, the coefficients of determination (R^2) show that the models explain only between 18% and 29% (for the standard models), 21% and 30% (for the semi-parametric models) of the variation in net income per hectare of cereals. Thus, this assumes that part of the variation in net income per hectare of cereals remains unexplained by the variables taken into account in these different models. However, these models remain satisfactory with respect to the results obtained in similar studies (Mendelsohn et al., 1994; Gbetibouo and Hassan, 2005; Dall'erba and Domínguez, 2016; Kurukulasuriya and Mendelsohn, 2006; and Ouedraogo et al., 2006).

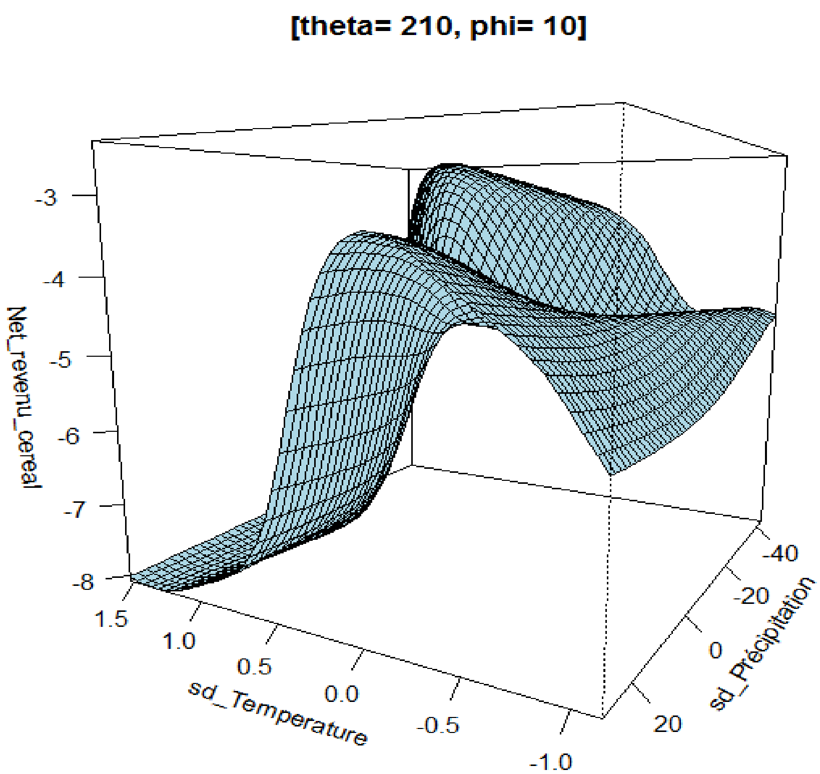
We also tested the specifications of the Ricardian model in its standard and semi-parametric forms using the Akaike Information Criteria (AIC) Bayesian model selection criterion. Thus, the comparison of the AIC statistics obtained (Table 4) reveals, as in the work of Egbendewe-Mondzozo et al. (2011), that the semi-parametric specifications of the Ricardian model are better than those of the standard model.

Considering the semi-parametric estimation of the Ricardian model, the results obtained are divided into two parts, a parametric part whose estimated coefficients are associated with the soil, socio-economic and exploitation variables (Table 2), and a second part of the results, which is a non-parametric estimation, particularly concerning the climatic variables whose flexibility in the model makes it possible to determine the nature of the relationship and the effect between them on the net income per hectare of cereal crops.

The results of the semi-parametric model reported in Table 4 indicate a significance of the functional form (non-parametric function of the combination of temperature and rainfall variability variables) at 1%. However, Figure 5 in 3D highlights the combined effect of temperature and rainfall variability on the net income per hectare of cereal crops, and the nature of the relationship between these variables.

The analysis of Figure 5 reveals that the curve obtained is in the negative segment of the y-axis of the graph. This shows that the simultaneous effect of temperature and rainfall variability is negative on the net income per hectare of cereal crops. In addition, an increase in rainfall variability leads to a decrease in net income from cereal crops. Similarly, temperature variability above 0.1°C decreases the net income per hectare of cereals. Moreover, Figure 5 reveals a non-linear and complex relationship between the variability of climatic parameters and the net income of cereal crops.

Figure 5: Simultaneous effects of temperature and rainfall variability on net income per hectare of cereals



Compared to the result of the semi-parametric model, results of the standard model estimation presented in Table 4 indicate that the coefficients of the linear terms of the climate variables are, respectively, negative, positive and statistically significant at 1%. Therefore, the negative sign of temperature variability on net income per hectare reveals a decrease in the latter, after its increase. This negative relationship could be explained by the fact that cereal crops require a significant amount of moisture. Thus, temperature increase with respect to the average will have a negative effect on the quantity harvested and could reduce the net income per hectare from this production. The positive sign of the coefficient of rainfall variability indicates that an increase in the level of rainfall variability would lead to an increase in the harvest and thus an increase in the net income per hectare from these crops.

The quadratic terms of the climate variables have opposite signs to the linear terms in the standard Ricardian model, which is consistent with the assumption that the relationship between climate and net cereal income is non-linear (Mendelsohn et al., 1994; Mendelsohn and Dinar, 2003). The coefficient sign of the quadratic term of mean rainfall variability indicates an inverted U-shaped relationship between net income per hectare and the level of rainfall variability. This implies that higher rainfall variability would increase the net income of these crops up to a given threshold, beyond which the increase in rainfall variability would result in a reduction in farmers' net income.

Analysis of results of the two models reveals that climate has a non-linear relationship on the net income per hectare of cereal crops, which is consistent with the available literature compared to the standard Ricardian model estimate (Deressa, 2007; Kurukulasuriya and Mendelsohn, 2006; Mendelsohn et al., 1994; Mendelsohn and Dinar, 2003; Seo and Mendelsohn, 2008a). However, it is observed that at the level of the semi-parametric model, this non-linear relationship is more complex than in the case of the standard model. Furthermore, it should be noted that the inclusion of linear and quadratic terms in the standard model may bias the results, given that the climate effect is captured in a rigid way according to the variation in temperature and rainfall.

Analysis of the coefficients of the soil variables (Table 4) reveals that, compared to parcels characterized by a Luvisol-type soil, the effects of Nitrosols and Lithosols soil types are positive on net income per hectare of cereal crops regardless of the type of estimate. There is a negative effect of nithosol types. This would be explained by its low fertility level and low water retention capacity in Togo. This result confirms that of Agossou et al. (2016) in Togo and Ouedraogo et al. (2006) in Burkina Faso, which also show that soil types negatively affect net agricultural income.

Considering socio-economic variables, household size has a positive effect on net income per hectare of cereal crops. However, these effects are not statistically significant and, therefore, do not significantly explain the net income per hectare of cereal crops. Compared to men, being a woman reduces the net income per hectare of cereal crops. This effect is statistically significant and can be explained by the fact that women spend less time on cereal production due to other activities.

The effect of the area cultivated on the net income per hectare of cereal crops is positive and statistically significant. However, to compensate for the low productivity of the land, farmers tend to increase the area under cultivation. This strategy increases production and leads to increase in farmers' income (Ouédraogo et al., 2010). This would explain why farm size has a positive and significant effect on net income from cereal crops. This result contradicts that of Ouédraogo (2006) and confirms that of Eid et al. (2006). In addition, the coefficient of education level is positive and statistically significant. This implies that, compared to farmers without any level of education, having at least primary level education improves the net income of cereal crops.

One of the contributions of this paper to the Ricardian literature is the analysis of the inclusion of market prices in the model. Price variables are a crucial component because these variables can not only capture market effects but can also be used to simulate the impact of future market fluctuations from the Ricardian model. Therefore, it is also crucial to define and use appropriate market price variables that are locally important. Thus, the prices of the different crops considered in this research are included in the different regressions of the Ricardian model (standard and semi-parametric model). The results reported in Table 4 reveal that the prices of different crops positively and significantly affect the net income per hectare of cereal crops at 1%. This result thus shows that an increase in the prices of these crops would lead to an increase in the net income of farmers. This is consistent with economic theory, which assumes a positive relationship between price increases and the supply of goods. Therefore, Togolese farmers, as price takers, will tend to follow the price variations of these different crops as one of the key factors in land use and decision making.

In the face of the effects of climate variability, it is clear that farmers are developing strategies in terms of responses to the impacts they are experiencing. Thus, we note the adoption of different adaptation strategies at the level of Togolese farmers. Analysis of the results reveals a statistically significant effect of up to 1% of the coefficients associated with some of the variables relating to these strategies on the net income per hectare of cereal crops. Indeed, the practice of agro-forestry to the detriment of cereal crops is a strategy that influences farmers' net income. To this effect, it can be observed that, at the level of farmers, this practice has a significantly positive effect on the net income per hectare of cereals. Therefore, substituting cereal production by agro-forestry or practicing it as a complementary activity improves the net income of cereal crop farmers.

Combination of crops and use of improved seed types are coping strategies practiced in most cases by farmers. Thus, analysis of the results reveals that the use of improved seeds negatively and significantly affects the net income of cereal crops. This result remains contradictory to the main objective of using these seeds. This can be explained by misuse of these seeds or the allocation of these seeds to another purpose such as food.

Table 4: Results of semi-parametric estimates of the Ricardian model according to crops

	Semi-parametric model coefficient	Standard Model coefficient
Temperature standard deviation	-	-0.302*** (-5.69)
Standard deviation square temperature	-	0.373*** (8.47)
Rainfall standard deviation	-	0.006*** (3.48)
Standard deviation square rainfall	-	-0.002** (-2.47)
Nitrosols soil	0.286* (1.83)	0.309** (2.03)
Lithosols soil	0.309*** (7.29)	0.292*** (6.56)
Nithosols soil	-0.193*** (-3.15)	-0.174*** (-2.99)
Age	0.001 (0.62)	0.001 (0.53)
Gender	-0.078** (-2.20)	-0.088** (-2.47)
Size	0.010 (1.29)	0.010 (1.25)
Level of education	0.091*** (3.90)	0.092*** (3.93)
Farm size	0.005*** (31.62)	0.005*** (5.23)
Price	0.004*** (11.34)	0.004*** (10.34)
Use of irrigation	-0.260* (-1.81)	-0.232 (-1.55)
Agro-forestry activity	0.412*** (8.35)	0.419*** (8.07)
Crop combination	0.185*** (5.55)	0.182*** (5.49)
Type of seed	-0.267*** (-4.81)	-0.274*** (-5.04)
Latitude	0.030 (1.22)	0.032 (1.43)
Membership to group	0.055 (1.04)	0.052 (0.97)
Semi date	-0.001** (-2.51)	-0.001** (-2.30)
Access to credit	-0.133 (-1.63)	-0.154** (-2.04)
Animal and livestock management	0.055 (1.48)	0.061* (1.66)
Constant	9.835*** (44.65)	9.768*** (48.24)
f(sd_Temperature,sd_Précipitation)	18.4***	
R^2	0.21	0.18
AIC	24,612.46	24,679
Fisher	8.42***	25.75***
Number of observations	7,090	7,075

(.) T-student; * Significant to 10% threshold, ** Significant to 5%, threshold *** Significant to 1% threshold

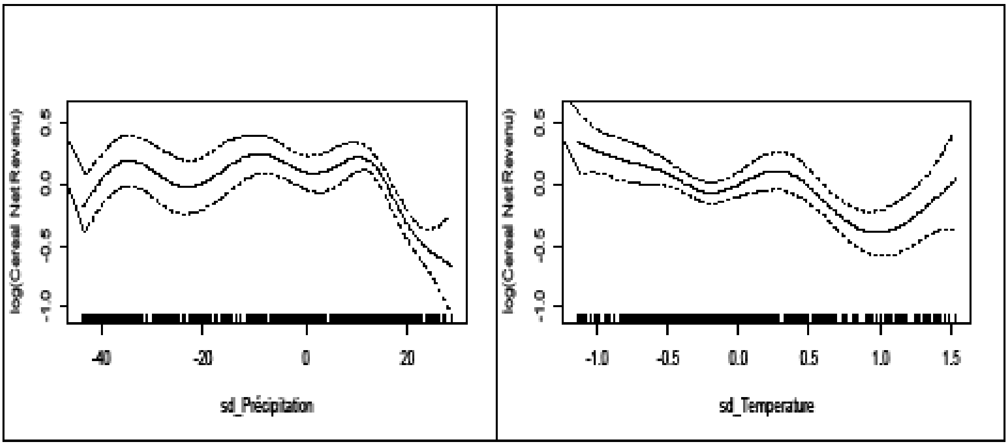
Source: Author

Assuming that climate variables can have additional effects on the change in net income per hectare of cereal crops, an aggregate form of the Ricardian semi-parametric model was estimated. Analysis of the result of the non-parametric parts, shown in Figure 6, reveals a non-linear effect of temperature and rainfall variability on the net income per hectare of cereal crops. However, the effect of rainfall variability has an inverted U-shaped trend and that of temperature variability has a U-shaped trend. Moreover, these non-linear relationships observed between the climatic variables and the net income per hectare of cereals with the additional-effect model tends towards the results of previous studies using the standard Ricardian model.

Among others, analysis of the figure shows that rainfall variability between 40mm and 20mm has a positive effect on net income per hectare. Beyond a rainfall variability of 20mm, there is a negative effect on net income per hectare. However, a rainfall variability of about -10mm has a maximum and positive effect on net income per hectare.

By considering the variability of the average temperature, the greater the variability of the average temperature, the lower the net income per hectare. Nevertheless, when the temperature variability is below 0.5°C, the effect is positive on the net income per hectare of cereals. Above 0.5°C, temperature variability has a negative effect on net income per hectare.

Figure 6: Aggregate effect of temperature and rainfall variability on net income from maize



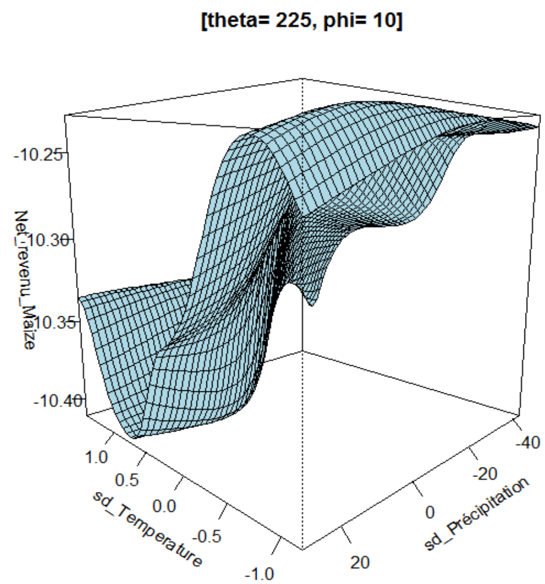
4.2.2 Effect of climate variability on net income per cereal crop

This section analyses the effect of temperature and rainfall variability on the net income of maize, sorghum and paddy rice. The results of the non-parametric part of the semi-parametric regressions are thus represented by Figures 7, 8 and 9 in 3D, respectively, for maize, sorghum and paddy rice.

Analysis of Figure 7 reveals a negative effect of temperature and rainfall variability on the net income of maize crop. In addition, temperature variability in excess of -0.5°C is found to reduce the net income of maize. However, for variability between -1°C and -0.5°C, net income increases and reaches its maximum. Considering the sorghum crop, there is also a negative effect of simultaneous temperature and rainfall variability on its net income per hectare. In addition, Figure 8 shows an inverted U-shaped relationship between rainfall variability and net income per hectare for this crop. An increase in temperature variability would lead to a decrease in net income per hectare.

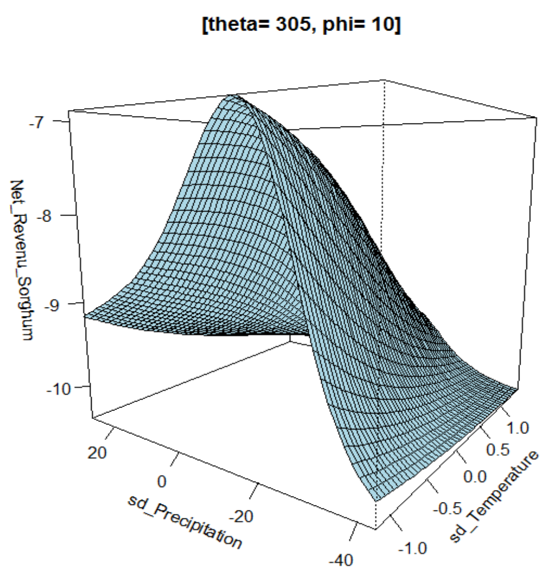
Analysis of Figure 9 highlights the nature of relationship and the effect of temperature and rainfall variability on net income per hectare of paddy rice. A simultaneous positive and negative effect of climatic variables on net income per hectare of paddy rice is thus observed. Therefore, a temperature variability of between -1°C and 0.5°C positively affects the net income per hectare. Beyond a temperature variability of 0.5°C, the net income per hectare of paddy rice decreases and becomes negative. In addition, there is a complex and non-linear relationship between climate variability and net income per hectare of rice.

Figure 7: Effect of temperature and rainfall variability on maize net income



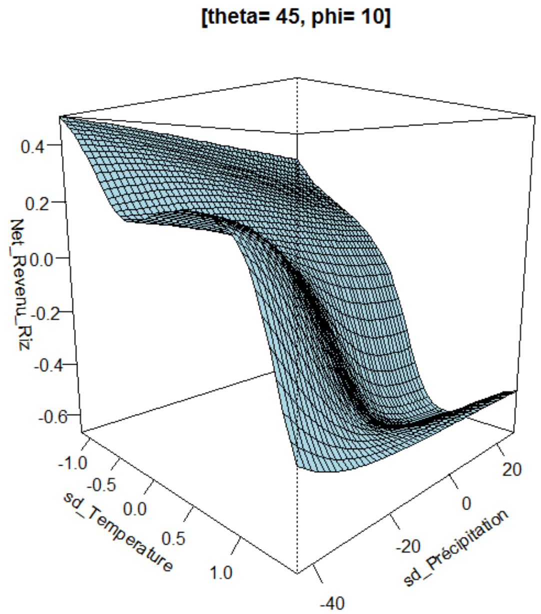
Source: Author

Figure 8: Effect of temperature and rainfall variability on sorghum net income



Source: Author

Figure 9: Effect of temperature and rainfall variability on maize net income



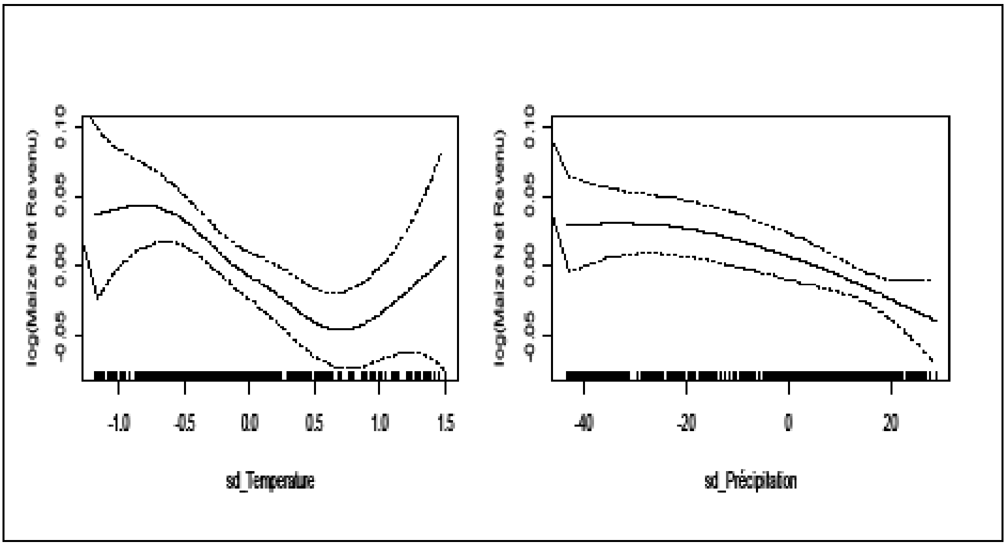
Source: Author

In a nutshell, the various figures above from the semi-parametric estimation of the Ricardian model reveal the existence of a non-linear relationship between the variability of temperature and rainfall on the net income per hectare of the various cereal crops. However, these results are in line with those existing in the literature on climate variability and agriculture (Kurukulasuriya and Mendelsohn, 2007; Seo et al., 2009; and Nhemachena et al., 2010), but the nature of the relationships becomes more complex in the estimation of the flexible forms taken by climate variables.

Considering the estimates of the aggregate forms of the Ricardian semi-parametric model, the results of the non-parametric parts represented by Figures 10, 11, and 12 show the nature of the relationship between temperature and rainfall variability on the net income per hectare of different cereal crops.

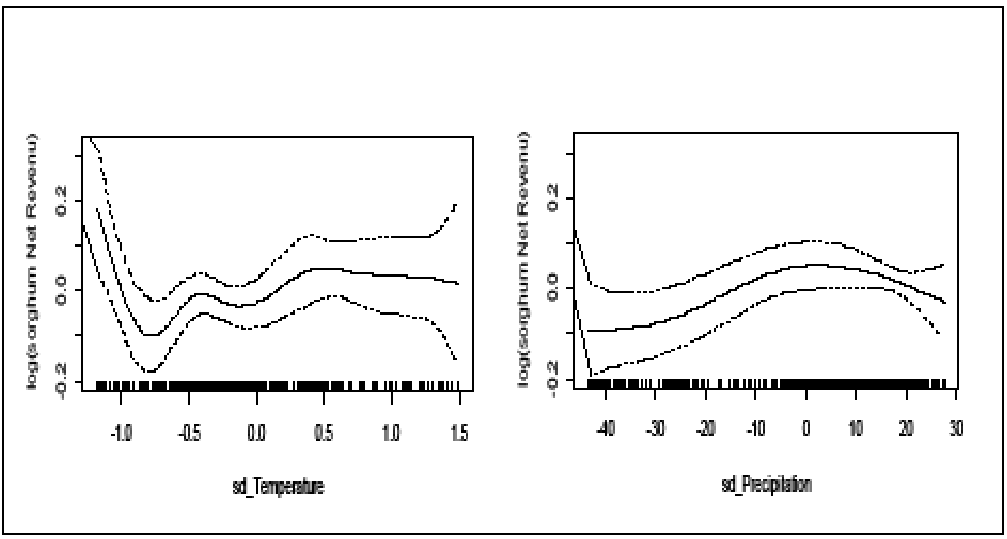
Analysis of the figures, therefore, reveals a U-shaped relationship between temperature variability and net income per hectare for maize and sorghum crops. With respect to rainfall variability, we observe that an increase in rainfall variability would increase the net income of maize and sorghum crops up to a threshold beyond which any increase would reduce the net income of these crops. The aggregate effect of temperature and rainfall variability on the net income of the rice crops reveals a linear decreasing relationship between temperature variability and net income. This relationship is non-linear with respect to rainfall variability.

Figure 10: Aggregate effect of temperature and rainfall variability on net income for maize



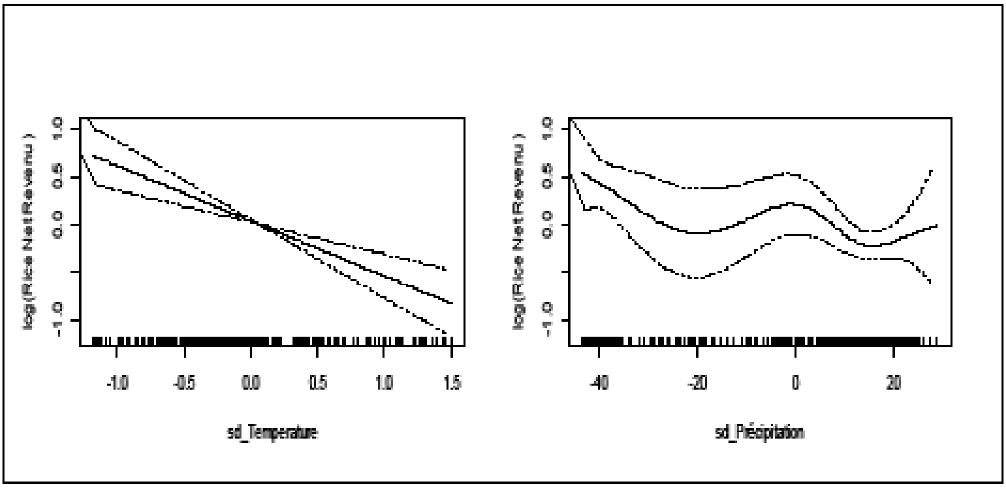
Source: Author

Figure 11: Effect of temperature and rainfall variability on sorghum net income



Source: Author

Figure 12: Aggregate effect of temperature and rainfall variability on net income from paddy rice



Source: Author

4.2.3 Elasticity of cereal crops net income with respect to variations in temperature and rainfall

In this section, we will estimate income elasticity for cereal crops. The results of the calculation of the elasticity are based on the semi-parametric regressions of the Ricardian model. The numerical derivatives obtained from the non-parametric estimation according to the variables of temperature and mean rainfall are used to calculate the net income elasticity of the different cereal crops. Since the dependent variable is the log of net income per hectare, the estimated equation is:

$$\log(y_i) = f(X_i) + \beta Z_i \, .$$

The percentage variation in net income of cereal crops in relation to the one percent change in temperature or rainfall, referred to as elasticity, is averaged over all farmers as follows:

$$e_{xy} = \frac{\partial y}{\partial x}\frac{x}{y} = \hat{f}'(x)e^{(f(x)+\hat{\beta}z)}\frac{x}{y}$$

Table 5 summarizes the calculated elasticity for all cereals, and for each of them according to temperature and rainfall variables. Analysis of these results reveals that the net income per hectare of cereal crops is sensitive to variations in climatic variables. However, this sensitivity is greater in relation to the variation in rainfall. In addition, there is a greater sensitivity of net income for maize compared to other crops.

Table 5: Income elasticity with respect to climate variability

	Cereals	Maize	Sorghum	Rice
Temperature	-0.001	-0.015	0.005	-0.001
Rainfall	-0.006	-0.060	-0.071	0.003

Source: Author

4.2.4 Future effects projections according to climate patterns

The results of different estimates have revealed that net income from cereal crops is very sensitive to climate. In this sub-section, we use elasticity to project the impact of variation of climatic parameters on Togolese agriculture.

Following Egbendewe-Mondzozo et al. (2011), and assuming that the value of elasticity of net income of a crop with respect to 1°C temperature variation is a% and the value of elasticity of net income with respect to 1% rainfall variation is b%, if the projected variation of temperature in degrees Celsius is c% and the projected variation of rainfall is assumed to be equal to d%, then knowing the average value m, of the net income of this crop, the variation of net income p is calculated by:

$$p = m(a * c + b * d)$$

Thus, we simulate the impact of climate variability on net crop income in 2025 and 2050 based on the results of climate models for specific reduced scenarios in West Africa (Representative Concentration Pathway 8.5) published by the IPCC in 2013. The following scenarios are taken into account:

Scenario 1: temperature increase of 1°C and rainfall decrease of 2.5% in 2025

Scenario 2: temperature increase of 2°C and 10% decrease in rainfall in 2050

The simulation results for the different scenarios presented in Table 6 show that in 2025, the combined effect of increased temperature and reduced rainfall would lead to a 15.8% reduction in the net income of cereal crops. Specifically, there will be a reduction in net income from maize and paddy rice crops of about 40.4% and 72.1%, respectively. In addition, in 2050, the simulations under scenario 2 show a more pronounced effect. These different results confirm the findings of previous studies such as those of Gadédjisso-Tossou et al. (2016) in Togo and Deressa (2006), which show that climate variability will have negative impacts on agriculture in African countries in the future.

Table 6: Impact of climate on cereal crops net income in 2025 and 2050

	% variation in net income of			
	Cereals	Maize	Sorghum	Rice
Scenario 1	-15.8%	-40.4%	24.2%	-46.5%
Scenario 2	-27.5%	-72.1%	62.0%	-98.2%

5.0 Conclusion and Policy Implications

The interest of this research was to assess the effects caused by climate variability through the variability of these components (temperature and rainfall) on the net income of cereal crops in Togo. Most of the recent studies in Togo on the effect of climate variability on agriculture have focused on the extent of damage caused to all agricultural products. However, a more important issue is to study how net cereal crop incomes are affected by temperature and rainfall variability. The Ricardian approach was adopted for this study because it implicitly takes into account farmers' adaptations to climate variability. Thus, to address some of the limitations of the standard Ricardian model, estimates were made by estimating a semi-parametric specification of the Ricardian model. The results revealed from the Akaike information criterion statistics that the semi-parametric specification is better than the standard Ricardian model specification.

The results also suggest that climate affects the net income of cereal crops. An increase in mean temperature variability decreases the net income of cereal crops, while an increase in rainfall variability increases net crop income. The results further suggest that there is a non-linear relationship between temperature variability and net crop income, and between rainfall and net crop income. These results are consistent with previous studies on the impact of global warming on agriculture, but this relationship is more complex with semi-parametric estimation. In addition, we also find that soil types and some socio-economic variables influence the net income of Togolese farmers. The estimated elasticity reveal that net crop income is sensitive to variations in climatic parameters, but less sensitive to temperature variation than to rainfall.

This paper also provides the impact of different scenarios of climate variability on net cereal income. We used two scenarios from RCP 8.5 (Representative Concentration Pathway 8.5) published by the IPCC in 2013. The predictions show that long-term variability in temperature and rainfall will have a negative impact on net income of all cereals. However, the impact will be greater over time (2050). In terms of adaptation strategies, the results of the estimates reveal that crop combination and agro-forestry practices reduce the effects of climate variability on the net income of cereal crops. The use of improved seeds does not contribute to increasing the net income of cereal crops.

The results of this paper highlight the impact of climate variability on the net income of cereal crops and the importance of farmers' adaptation strategies in improving their net income and reducing the effects of climate on them. Thus, the implications of economic policies in terms of addressing constraints to the adoption of strategies should be promoted, coupled with better understanding of the effects of climate variability. Compared to the adaptation strategies already implemented by farmers, it would be interesting to encourage the use of these strategies that improve farmers' income and to promote others. Regarding improved use of selected seeds, it would be interesting to intensify awareness on their better use, given the negative effects of their application on net cereal income.

By considering the projected effects in relation to different cereal crops, we note that the effects will be greater on the net income of rice and maize crops. These crops are more cultivated and consumed and it would be interesting to intensify actions to reduce the effects of climate variability on their income.

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Annex

Annex Table 1: Semi-parametric model estimation results per cereal crop

Variables	**Maize**	**Sorghum**	**Rice**
	Coefficient	Coefficient	coefficient
Nitrosols soil	0.275	4.064***	-0.524
	(1.58)	(6.43)	(-0.83)
Lithosols soil	0.248***	-0.013	1.023***
	(4.63)	(-0.15)	(8.21)
Nithosols soil	-0.174**	-0.189	0.210
	(-2.34)	(-0.78)	(0.72)
Age	-0.002	0.002	0.001
	(-1.25)	(0.70)	(0.27)
Gender	-0.084*	0.015	-0.165
	(-1.95)	(0.21)	(-1.61)
Household size	0.003	0.018	0.020
	(0.28)	(1.15)	(0.88)
Education level	0.019	-0.031	0.059
	(0.67)	(-0.69)	(0.89)
Farm size	0.006***	0.004***	0.018***
	(30.02)	(18.24)	(13.92)
Price	0.005***	0.005**	0.003*
	(6.09)	(2.49)	(1.67)
Use of irrigation	-0.260	-0.536	-0.616
	(-1.62)	(-1.60)	(-1.22)
Agro-forestry practice	0.390***	-0.093	-0.088
	(6.23)	(-0.84)	(-0.60)
Combination of crops	-0.009	-0.026	0.275
	(-0.22)	(-0.39)	(1.10)
Type of seed	0.006	-0.026	-0.071
	(0.11)	(-0.18)	(-0.45)
Latitude	0.060**	0.001	0.021
	(2.06)	(0.01)	(0.27)
Membership to a group	0.049	-0.029	0.099
	(0.75)	(-0.27)	(0.67)
Semi date	0.001	-0.0004	0.0003
	(-0.36)	(-1.08)	(0.53)
Access to credit	0.050	0.085	-0.283
	(0.50)	(0.54)	(-1.19)
Livestock management	0.036	-0.097	0.212**
	(0.79)	(-1.25)	(2.02)
(Intercept)	9.070***	9.640***	9.755***
	(31.91)	(18.13)	(12.69)
	17.33	9.20	13.56
R^2	0.28	0.30	0.25
Number of observations	3,041	1,095	901

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

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