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WEST AFRICAN SCIENCE SERVICE CENTER ON CLIMATE CHANGE AND ADAPTED LAND USE

UNIVERSITE DE LOME

ASSESSING THE IMPACT OF CLIMATE CHANGE ON SMALLHOLDER FARMERS' CROP PRODUCTION-BASED REVENUE IN TOGO

A Thesis

by

Agossou GADEDJISSO-TOSSOU

Submitted to the West African Science Service Center on Climate change and Adapted Land Use, Université de Lomé

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

November 2014

Major Subject: Climate Change and Human Security

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Approved by:

Chair of Committee,	Georges A. Abbey
Committee Members,	Amadou Thierno Gaye
	Jean Mianikpo Sogbedji
Director of Program,	Kouami Kokou

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ABSTRACT

Assessing the Impact of Climate Change on Smallholder Farmers' Crop Production-based Revenue in Togo (November, 2014)

Agossou Gadedjisso-Tossou, Dipl. Ing., Université de Lomé

Chair of Advisory Committee: Dr Georges A. Abbey

This study employs a Ricardian approach to measure the impact of climate change on smallholder famers' crop production-based revenue in Togo. A regression of farmer's revenue on climate, soil and other socioeconomic variables was conducted to capture farmer-adapted responses to climate variations. The analysis was based on cross-section data of the National Agricultural Census conducted during 2012-2013 agricultural season and average long-term temperature and rainfall data from 1961 to 2013 pooled over the 35 districts of Togo. Results indicate that climate has a nonlinear effect on net revenue from crop production. In rainy season, the marginal impact of the temperature on farmers' net revenue is negative, while the one for the rainfall is positive. The scenarios of decrease of the rainfall and/or increase of the temperature are very detrimental to Togolese agriculture, because of the already harsh climatic conditions in the country. The analysis of farmers' perception of climate change reveals a high increase in temperature and a high variability in rainfall pattern. Education attainment, farming experience, access to extension services and credit as well as climate information are factors that enhance farmers' adaptive capacity to climate change and variability. Consequently, the government should design policies aimed at improving the aforementioned factors.

Keywords: Climate change, net revenue, Ricardian approach, marginal impact, perception, adaptive capacity, Togo.

Résumé

Cette étude utilise l'approche Ricardienne pour évaluer l'impact des changements climatiques sur le revenu des petits exploitants agricoles issu de la production végétale au Togo. La méthode consiste à exprimer le revenu net en fonction des variables climatiques, édaphiques et socio-économiques afin de capter l'adaptation des producteurs aux changements climatiques. L'analyse a exploité les données d'une enquête réalisée dans le cadre du Recensement National Agricole (RNA) de la campagne 2012-2013, d'une part, ainsi que les données de climat (température et précipitation) de 1961 à 2013 sur les 35 préfectures du Togo, d'autre part. Les résultats de l'étude établissent le non linéarité de la relation entre le revenu net agricole et le climat. En saison des pluies, l'impact marginal de la température sur le revenu net agricole est négatif tandis que celui de la précipitation est positif. A la lumière des conditions climatiques déjà difficiles, les scenarios de diminution des précipitations et/ou d'augmentation des températures sont très dommageables à l'agriculture au Togo. L'analyse de la perception des producteurs des changements climatiques montre une augmentation des températures et une très grande variabilité dans le régime pluviométrique. Le niveau d'éducation, l'expérience en agriculture, l'accès aux services de vulgarisation, de crédit et à l'information sur le climat sont des facteurs qui accroissent la capacité d'adaptation des producteurs aux changements et aux variabilités climatiques. En conséquence, le gouvernement devrait élaborer des politiques visant à améliorer les facteurs mentionnés ci-dessus.

Mots clés: Changements climatiques, revenue net, approche Ricardienne, impact marginal, perception, capacité d'adaptation, Togo.

DEDICATION

I dedicate this work to my beloved parents, Marcelin Gadedjisso and Sivome Agbessinou, and my siblings for their love and support.

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"Glory to the Almighty God"

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LIST OF ABBREVIATIONS

AR4	Fourth Assessment Report
CEEPA	Centre for Environmental Economics and Policy in Africa
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNM	Direction Nationale de la Météorologie
DSID	Direction des Statistiques Agricoles, de l'Informatique et de la Documentation
ECLAC	Economic Commission for Latin America and the Caribbean
ESDB	European Soil Database
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organisation
FCFA	Franc des Communautés Financières d'Afrique
GCM	Global Climate Model
GDP	Gross Domestic Product
HWSD	Harmonized World Soil Database
IAMs	Integrated Assessment Models
ICAT	Institut de Conseil et d'Appui Technique
IIASA	International Institute for Applied System Analysis
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Conversion Zone
ITRA	Institut Togolais de Recherche Agronomique
MIROC	Model for Interdisciplinary Research on Climate
MNL	Multinomial logit
MRP-CCHS	Master Research Program- Climate Change and Human Security
PNIASA	Programme National d'Investissement Agricole et de Sécurité Alimentaire

UNDP	United Nations Development Program
RCP	Representative Concentration Pathways
RNA	Recensement National Agricole
SOTER	SOil and TERrain database
SOTWIS	Soil, TERrain and World Inventory of Soil database
SRES	Special Report on Emission Scenarios
USAID	United States Agency for International Development
VIF	Variance Inflation Factor
WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use

CHAPTER 1: INTRODUCTION

1.1 Problem Statement

The Intergovernmental Panel on Climate Change (IPCC, 2007) defines climate change as statistically significant variations in climate that persist for an extended period, typically a decade or longer. It includes shifts in the frequency and magnitude of sporadic weather events as well as the slow continuous rise in global mean surface temperature. Climate change has become our new reality. It brings changes in weather patterns that can have serious repercussions for all of us, modifying seasonal cycles, harming ecosystems and water supply, affecting agricultural farming systems and food production, causing sea-levels to rise. The problem is expected to be more severe in Africa, where current information is the poorest, technological change the slowest, and the domestic economies depend heavily on agriculture (Mendelsohn et al., 2000).

African farmers have adapted to a certain amount of climate variability, but climate change may well force large regions of marginal agriculture out of production in Africa. Agriculture is extremely vulnerable to climate change (IPCC, 2001). Experts are concerned that the agriculture sector in Africa will be especially sensitive to future climate change and any increase in climate variability. Besides, with the rapid population growth especially in developing countries, food insecurity has become a major threat in these countries. Globally, countries in West Africa are among the most vulnerable to the effects of climate change because of the reliance of much of the population on agriculture, particularly rain-fed agriculture. The vulnerabilities are worsened, given a host of biophysical and human-related issues in the region, including erosive rainfall, recurring drought, soil qualities and fertility, low input farming systems, decreased fallow period, deforestation, frequent bush fires, and overgrazing (USAID, 2011).

In Togo, agriculture remains the most important sector of the economy and 70% of the population practice agriculture as their main activity (MERF, 2001). Agriculture accounts for 38% of Togo's gross domestic product (food crops 26.0%, cash crops 3.4%, livestock products 5.1%, fishery products and aquaculture 1.4%, and forestry production 2.1%) (ROT, 2009). In addition, agriculture supplies more than 20% of the exportation revenue (MERF, 2010). Despite its high contribution to the overall economy, agriculture in Togo is predominantly rain-fed and hence fundamentally dependent on the vagaries of weather. Less than 1% (20,000 hectares) of the cultivated land in Togo are irrigated (FAO, 2005).

Therefore, changes in rainfall conditions impact both the performance of agricultural sector and the country's total GDP.

The mean annual temperature has increased by 1.1˚C since 1960, an average rate of 0.24˚C per decade in Togo (McSweeney et al, 2009). The same authors also disclosed that the annual rainfall in Togo is highly variable on inter-annual and inter-decadal timescale. Rainfall over Togo was particularly high in the 1960s; it decreased to particularly low levels in the late 1970s and early 1980s, causing an overall decreasing trend in the period from 1960 to 2006, an average 2.3 mm per month (2.4%) per decade. In addition, the 2008 flooding in Togo destroyed 24,956 hectares, representing 56% of affected farmers' cultivated areas (MERF, 2010).

In Togo, the impact of climate change on the crops and ecosystems, livestock farming and fishing is globally negative (MERF, 2007). Known as staple food in Togo, maize and sorghum are particularly vulnerable to climate change because of their strong sensitivity to the water stress especially at flowering stage. Based on General Climate Model, the mean annual temperature is projected to increase by 1.0 to 3.1˚C by the 2060s, and 1.5 to 5.3˚C by the 2090s in Togo. Precipitation-wise, a wide range of changes, covering a similar range of increases as decreases is projected (McSweeney *et al*, 2009). In addition, the IPCC's 2025, 2050 and 2100 scenarios have projected a decrease in the production of the major crops to 5%, 7% and 10%, respectively (MERF 2010).

Adaptation is widely recognized as a vital component of any policy response to climate change. It is a way of reducing vulnerability, increasing resilience, moderating the risk of climate impacts on lives and livelihoods, and taking advantage of opportunities posed by actual or expected climate change (Acquah-de Graft and Onumah, 2011). The literature on adaptations also makes it clear that perception is a necessary prerequisite for adaptation. However, perceptions are influenced not only by actual conditions and changes, but are also influenced by other factors. For instance, a study by Gbetibouo (2009) found that education seems to decrease the probability that the farmer will perceive long-term changes in rainfall. This means that educated farmers are more likely to see that rainfall does not have a significant trend over the long run than other farmers. In addition, with experience, farmers are more likely to perceive changes in temperature. Moreover, farmers who have access to water for irrigation purposes are unlikely to perceive any change in temperature or rainfall. Also, access to extension, on the other hand, increases the probability of perceiving change in temperature. Finally, farmers with highly fertile soil are less likely to perceive change in temperature but more likely to perceive change in rainfall. Despite the importance of perceptions and adaptation to climate change, in the context of Togo, a very few studies have examined farmers' perceptions and adaptation to climate change. Also, in order to enhance policy towards tackling the challenges that climate change poses to farmers, it is important to have knowledge of farmers' perception on climate change, potential adaptation measures, and factors affecting adaptation to climate change.

Decision makers are therefore particularly keen to be informed about the possible disastrous effects of climatic changes on agriculture, about farmers' perception of these changes and adaptation measures for reducing them. Thus, this study purports to assess the economic impact of Climate Change on crop production and smallholder farmers' perception and adaptation to these changes in Togo.

1.2 Objectives

The overall objective of this study is to analyse the economic impact of climate change on crop production and smallholder farmers' perception and adaptation in Togo.

The Specific objectives of this study are:

- to analyse the relationship between farmers' net revenue and climate variables (rainfall and temperature);
- to identify factors explaining significantly farmers' net revenue;
- to determine the marginal impact of temperature and rainfall on farmers' crop revenues;
- to evaluate the effects of climate change on farmers' revenue on the basis of specific climate change scenarios for Togo (RCP8.5); and
- to capture farmers' perceptions of climate variability and change and the types of adjustments they have made in their farming practices in response to these changes.

1.3 Research Questions

Considering the findings of climate change research in Togo and other regions of the world, some questions of interest can be asked:

- What is the relationship between agriculture net income and climate variables?
- What are the factors that explain significantly the net income for agriculture?
- What is the impact of climate variability on agricultural profitability?

- Do farmers perceive climate change to have occurred already and if so have they begun to adapt to it? and
- What long term approaches should be recommended to improve the adaptive mechanisms?

1.4 Hypotheses

The assumptions of this study are:

- Temperature and rainfall have a quadratic relationship with farms crop net revenues;
- Climate variables are significant determinants of farmers' crop net revenue;
- Farmers' crop net revenue from crop production are sensitive to climate;
- Scenarios of increase in temperature and or decrease in the rainfall are detrimental to farmers' crop net revenue; and
- Most farmers' perception of changes in the climate and adaptation to them.

1.5 Thesis Structure

This thesis is composed of four further chapters. Chapter 2 reviews studies on the impact of climate change on agriculture and revisits the methods employed and key results from these studies. Chapter 3 details the methodology used in this study, while chapter 4 provides an overview of its main results. Finally, chapter 5 concludes with policy implications about this study. Additional information is presented in appendices.

CHAPTER 2: LITERATURE REVIEW

2.1 Climate Change Impacts on Agriculture

Country-specific studies on the climate change impacts expected for the agricultural sector in most low income countries are scarce, in part due to a lack of data availability. A study by Hulme (1996) revealed that there are four ways in which climate would have a physical effect on crops: changes in temperature and precipitation, atmospheric carbon content, water availability, and increased frequency of extreme climate events such as flood and drought.

First, changes in temperature and precipitation will alter the distribution of agro-ecological zones. Changes in soil moisture and content and the timing and length of growing seasons will be affected in various ways in different parts of the world. Rosenzweig and Hillel (1995) stated that in middle and higher latitudes, higher temperatures will lengthen growing seasons and expand crop producing areas pole-ward, thus benefiting countries in these regions, while less fertile soils in higher latitudes will temper some of the gains of an extended growing season. In contrast, in lower latitudes, it is expected that higher temperatures will adversely affect growing conditions.

Second, carbon dioxide effects are expected to have a positive impact due to, for example, greater water use efficiency and higher rate of photosynthesis (Kurukulasuriya and Rosenthal, 2003). Also, rising carbon dioxide concentrations in the atmosphere are important to agriculture because they increase the rate of photosynthesis and water use efficiency. However, the net result may be moderated by costly pest and weed infestations (Rosenzweig and Hillel 1995). In addition, Amouzou *et al* (2013) found that increase in atmospheric CO2 concentration by 400-550 vpm enhanced maize grain yield by 3 to 11% but that positive effect did not offset the depressive effect of increased temperature on Ferrralsols in Coastal Western Africa. Jennifer and Acock (1986) indicated a limited response of maize yield to CO2 enriched environment in nutrient-stress conditions.

In addition, water availability (or runoff) is a critical factor in determining the impact of climate change in many places, particularly in Africa. A number of studies suggested that precipitation and the length of the growing season are critical in determining whether climate change positively or negatively affects agriculture (Hulme, 1996).

Finally, according to Kurukulasuriya and Rosenthal (2003), agricultural losses can result from climatic variability and the increased frequency of extreme events such as droughts and floods or changes in precipitation and temperature variance. As outlined in Rosenzweig and Hillel (1995), a higher frequency of droughts is likely to increase pressure on water supplies for numerous reasons, ranging from plant transpiration to allocation. In contrast, increases in rainfall intensity in other regions can lead to higher rates of soil erosion, leaching of agricultural chemicals, and runoff that carries livestock waste and nutrients into water bodies.

Hulme (1996) overlooked the fact that one way climate change can affect agriculture in coastal areas. That is sea level rise, which can inundate producing lands. In addition, it can also increase the amount of salt in these producing lands, making some plants to have a stunted growth there. This particular point has been mentioned by Keane et al (2009).

Impacts of climate variability and change on the agricultural sector are projected to steadily manifest directly from changes in land and water regimes, the likely primary conduits of change. Changes in the frequency and intensity of droughts, flooding, and storm damage are expected. Climate change is expected to result in long-term water and other resource shortages, worsening soil conditions, drought and desertification, disease and pest outbreaks on crops and livestock, sea-level rise, and so on. Vulnerable areas are expected to experience losses in agricultural productivity, primarily due to reductions in crop yields (Rosenzweig et al, 2002, as quoted in Kurukulasuriya and Rosenthal, 2003).

Most of the scenarios reviewed by Keane et al (2009) have either formed part of the Fourth Assessment Report (AR4) or have drawn on the IPCC Special Report on Emission Scenarios (2000). Regarding the results of these studies, all regions will experience an increase in temperatures towards the end of the current century; this is accompanied by predicted changes in precipitations (though to a much larger degree in terms of variability). In terms of the aggregate impact on agricultural production, it is established that a greater divergence between regions in terms of output is likely to happen. That is, for the most part, the more southern and equatorial developing countries are expected to lose in terms of agricultural production, whilst developed countries based in the north are likely to gain.

2.2 Review of Methodological Approaches Used to Assess Impact of Climate Change on Agriculture

Several methods have been developed to estimate the impact of the climate on agriculture. These methods can be grouped in two main categories (Bazzaz, 1997, as cited by Ouedraogo et al. 2006): the structural modelling of the agronomic response based on controlled experiments (the production function approach), and modelling taking into account the link between crop production and the farmers' economic management decisions, based on theoretical specification (the Ricardian approach).

Rosenzweig and Iglesias (1994) developed the production-function approach to evaluate the impact of climate change on USA agricultural sector. This approach is based on the existence of a production function for each crop, which links its yield to the physical, biophysical and biological environment. In the same year, many studies used this approach to evaluate the impact of the climate on crop production, for example, Reilly et al. (1994), and Rosenzweig and Parry (1994) for world food supply. In addition, Rao and Sinha (1994) used this method to assess the impact of the climate change on wheat production in India. Kumar and Parikh (2001) evaluated the impact of climate modifications on rice and wheat by relying on this method in India. Regarding the variables used, the aforementioned studies simulated crop responses to change in climate (temperature, precipitation, solar radiation, and relative humidity), management variables (irrigation, adaptation strategies), soils types and different levels of CO_2 in the atmosphere.

Moreover, Turpie et al. (2002)—as cited by Kabubo-Mariara and Karanja (2006) —analysed the economic impact of climate change in South Africa by using production function approach to measure the natural capital lost from global warming. They predicted that the impact of climate change on rangelands will be positive, with the fertilization impact of CO_2 outweighing the negative effects of reduced precipitation. However, they found that the impact of climate change on maize production will be negative both 'with' and 'without' CO_2 fertilization. Also, Quiroga Gómez and Iglesias (2005) used crop production functions to analyse global change impacts in Spain. These authors utilized panel data to estimate the relationship between production (such as tonnes per hectare) as a function of socio-economic and climate variables in various agro-climatic zones. In addition, the impacts of various technological variables were also included such as machinery value, fertilizer use, pesticide imports, and percentage of irrigated land for production of wheat, grapes, olives and oranges. Using the production functions, these authors succeeded in capturing the relationship between crop production (tons/ha) and the various inputs used to obtain this output. But they failed to take into account the variables related to the economic, social and environmental changes: e.g. farmers' behaviour in response to climate change and institutional variables. Therefore, this approach is subject to some criticisms (Mendelsohn et al., 1994; Kabubo-Mariara and Karanja, 2006; Ouedraogo et al., 2006 etc).

Originally presented by Mendelson et al (1994) to measure the value of climate in the United States agriculture, the Ricardian model is a cross-sectional analysis of the impact of climate on land value or farm revenue. The technique has been named the Ricardian method because it is based on the observation made by Ricardo (1817)—as cited by Deressa (2006)—that land values would reflect land productivity at a site under perfect competition. Generally using cross-sectional data, Ricardian analyses regressed the chosen productivity proxy (land value or net revenues) on climatic, agronomic and input variables to quantify the impact of climate change. Mendelsohn et al. (1994) estimated the influence of agro-climatic factors on USA farm land values. The authors deployed two models at the county level using different data weights. They first use a uniform climate change scenario of a 5°F temperature increase and an 8% rise in precipitation. Under these conditions, farm land values are expected to decrease by between US$119 billion and US$141 billion, according to the crop-land model. This represents an annual decrease of about 5% in 1982 gross farm income. However, when using the crop-revenue model, farm land values rise by between US$20 billion and US$35 billion which represent an annual increase in gross revenues of about 1%. It is assumed that farmers choose agricultural activities in order to maximise revenue given the environmental conditions (Blanc, 2011).

In addition, Ouedraogo et al. (2006) disclosed that land value is measured in terms of the net yield per acre of land [value of output minus inputs (excluding land rents)]. In a competitive market, land rent equals the net yield of the highest and best use of land. Farm value is calculated as the present value of future land rents. If the interest rate, rate of capital gains and capital per acre are equal for all parcels of land, then farm value is proportional to land rent. This study regressed the net revenue of crops on several variables: climate, soil, relevant hydrology and socio-economics. It tests three models (one without adaptation, one with adaptation, and one with a dummy zone variable). The authors established that if the temperature increases by 1°C, revenue will fall by 19.9 US$/ha. If precipitation increases by 1 mm/month, net revenue increases by 2.7 US$/h. In addition, the study revealed that some variables used in the regression can be effective as adaptation options. Extension service and irrigation are significant and positively affect net revenue. Furthermore, they used Climate Change (IPCC) uniform scenarios to show that 5°C increase in the temperature correspond to farmers' losing 93% of their net revenues obtained from crops; farmers would also lose their entire net revenue from crops if precipitations decreased by 14%. Similar studies undertaken in Cameroon by Molua and Lambi (2006) established that 5°C increase in the temperature would cause net revenues to fall by $1.7 billion and 14% decrease in precipitation would cause them to fall by $3.8 billion.

Kumar and Parikh (1998) and Sanghi et al. (1998) employed the net revenue approach and used pooled observations from 1966 to 1986 for India. Kumar and Parikh (1998) found that the effect of temperature is negative. The impact of precipitation is positive but is smaller in magnitude than the temperature effect, so the global effect is negative. They estimated an 8.7% decrease in net revenues when considering a uniform climate scenario of +2°C and +7% mean precipitation change. Under the same scenario, Sanghi et al. (1998) estimated a larger decrease in farmers' net revenues (12.3%). Under no change in precipitation and a slight temperature increase (+1°C) scenario, Sanghi et al. (1998) estimated revenue effect (-8.8%) is also larger than those of Kumar and Parikh (1998) (-3.2%). Controversially, ECLAC (2011) used crop yield in Jamaica instead of land value or net revenue as the dependent variable. ECLAC justified this by saying that Jamaica has underdeveloped property markets, which make land value difficult to determine and hence makes the original Ricardian model inapplicable. Therefore, ECLAC (2011) used the aforementioned modified version of the Ricardian model where crop yield is the dependent variable.

Several other studies applied Ricardian analyses to assess climate impact on agriculture in Africa. These studies were published as discussion papers by the Centre for Environmental Economics and Policy in Africa (CEEPA), located in University of Pretoria, South Africa. They include studies in Kenya (Kabubo-Mariara and Karanja, 2006), Egypt (Eid et al., 2006), South Africa (Benhin, 2006 and Gbetibouo and Hassan, 2005), Senegal (Sene et al., 2006), Zambia (Jain, 2006), Zimbabwe (Mano and Nhemachena, 2006), Ethiopia (Deressa, 2006). In detail, Kabubo-Mariara and Karanja (2006) showed that increased winter temperatures are associated with higher crop revenue, but increased summer temperatures have a negative impact. Increased precipitation is positively correlated with net crop yield. They also established that andosols, irrigation and household size are positively correlated with revenue, but livestock ownership, farm size and wage rates are inversely correlated with crop revenue. While Mano and Nhemachena (2006) estimated that Zimbabwean net revenues will decrease by 31% and 36% relative to the mean of the sample when temperature increases by 2.5°C and 5°C, respectively. Climate drying is less damaging: net revenues are expected to fall by 27% and 28%, respectively in both scenarios predicting a decrease of 7% and 14% in rainfall.

Eid et al. (2006) used four models, namely standard Ricardian model, model with linear term of hydrology, model with linear and quadratic terms of hydrology and model with the hydrology term and heavy machinery to assess the climate impact on Egyptian agriculture. They showed that a rise in temperature would have negative effects on farm net revenue in Egypt. In addition, they found that the marginal impact of temperature was -968.94US$, +26.17 US$, +150.96 US$, and -77.78 US$, per hectare for the four models, respectively. They used the scenarios of +1.5°C and +3.6°C increase in the temperature. As a result, they disclosed that high temperatures will constrain agricultural production in Egypt.

A study by Sene et al. (2006) established that farmers in Senegal have a low net revenue and suggested that small rain-fed farms are highly vulnerable to climate change. The study also established that farmers have several ways of adapting to climatic constraints: diversifying crops, choosing crops with a short growing cycle, weeding early in the north and late in the south, prayer, and so on.

UNDP (2011) has undertaken the econometric analysis of climate change effect on households in Togo by using the Ricardian approach. In addition to climate variables such as temperature and precipitation normal, UNDP (2011) has taken into account the number of agricultural machines, fertiliser consumption, percentage of agricultural population, percentage of irrigated area and arable lands as other variables. Time series data were used in the study which covered 1960 to 2010. It was found out that climate variables explained up to 33.8% the variation of the agricultural added value in Togo. In addition, UNDP (2011) disclosed that in short term, an increase of temperature and precipitation will affect positively the agricultural added value while a quadratic increase of the same climate variables will have a negative impact on the latter. These results mirrored those found by Molua (2009) for Cameroun and Kabuko-Mariana and Karanja (2006) for Kenya.

Mikémina (2013) used the Ricardian approach to measure the effect of climate change on agriculture performance in Togo, using time series data from the period 1971-2004. He found out that there exists a non-linear relationship between agricultural added value and recorded precipitations during the cropping period. This is a confirmation of the results of Ouedraogo et al. (2006) in Burkina Faso (mentioned above) and Kabubo-Mariara and Karanja (2006), who suggested a non-linear relationship between temperature and revenue, on the one hand, and between precipitation and revenue, on the other. In addition, Mikemina (2013) pointed out that marginal impacts are mostly in line with the Ricardian model, showing that marginally increasing precipitation during rainy season would increase net farm income, but reduce by the square terms of this season. Furthermore, he argued that other variables, such as ratio of irrigated farm land and farm labour, are found to have positive impact on net farm value. The Ricardian model has some merits, based on the different results of these authors.

An interesting data-related feature of the Ricardian model is that different impacts are expected depending on the current climate in the region considered. For example, Reinsborough (2003) concluded that Canada is expected to benefit from global warming (as cited by Blanc, 2011), whereas warm regions are expected to suffer economic losses from global warming. For instance, Kurukulasuriya and Mendelsohn (2008) examined the impact of climate change on cropland in Africa, using a Ricardian cross-sectional approach and data from 11countries (Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia, and Zimbabwe). They established that annual net revenue is regressed on climate and other variables. The study confirmed that current climate affects the net revenues of farmers across Africa. Furthermore, the results revealed that in 2020, climate change could have strong negative impacts on currently dry and hot locations. By 2100, dryland crop net revenues could rise by 51%, if future warming is mild and wet but fall by 43%, if future climates are hot and dry. The crop net revenues of currently irrigated farms are likely to be least affected. Similarly, Maddison et al. (2006) used the same set of data as Kurukulasuriya and Mendelsohn (2008) and observed that countries with warmer climates suffer greater losses. For instance, land values are expected to drop by 19.9% in Burkina Faso and by up to 30.5% in Niger. They found that, on the contrary, losses in cooler countries are less significant. For example, estimated land values in Ethiopia and South Africa fall by 1.3% and 3%, respectively.

The Ricardian method is a cross-sectional approach. It assumes that cross-sectional comparisons provide useful insights into long-term intertemporal changes (Kurukulasuriya *et al*, 2006). The Ricardian approach is preferred to the traditional estimation methods, given that instead of ad hoc adjustments of parameters that are characteristic of traditional approach, this technique automatically incorporates efficient adaptations by farmers to climate change (World Bank, 2003). Also, the use of net revenues in the Ricardian approach reflects the benefits and costs of implicit adaptation strategies (Mendelsohn et al., 1994). In addition, applying this model is cost effective, since secondary data on cross-sectional sites can be easily collected on climate, production and socio-economic factors (Deressa and

Hassan, 2009). Besides, another advantage of the Ricardian model highlighted by Ouedraogo *et al*. (2006) and Benhin (2006) is that it is used for a comparative assessment of with and without adaptation scenarios in agriculture. In other words, it corrects the bias in the production function approach by using socio-economic data on the value of land. By directly measuring farm prices or revenues, the Ricardian approach accounts for the direct effects of climate on the yields of different crops as well as the indirect substitution of different inputs, the introduction of different activities and other potential adaptations to different climates (Mendelsohn *et al*. 1994). It is also attractive, because it includes not only the direct effect of climate on productivity but also the adaptation response by farmers to local climate. According to Kurukulasuriya and Mendelsohn (2008), a final positive about the Ricardian method is that it reflects current agricultural policies. If countries subsidize specific inputs or regulate crops, these policies will affect farmer choices. The Ricardian results will consequently have these distortions embedded in the results. For example, if a country mandates that a fraction of cropland be devoted to a certain crop, one may well see more of that crop in that country than elsewhere. However, it should be noted that the Ricardian approach is subject to some criticisms.

Despite the popularity of the Ricardian approach it has several limitations. Early Ricardian studies of agriculture (Mendelsohn *et al*., 1994; 1996) have been criticized because they did not include irrigation and other sources of water in the analysis (Darwin, 1999). These studies have relied solely on a district, province or county's climate to predict agricultural outcomes. However, such defined area-specific climate does not provide a good indication of the availability of either surface or groundwater because these supplies often come from watersheds that extend far beyond a district/province/county (Mendelsohn and Dinar, 2003). Given the importance of water in agricultural outcomes, it is necessary to estimate the total flow of water to a given geographical area in order to assess the true impact of climate change on agriculture (Benhin, 2006). To address this shortcoming, Mendelsohn and Dinar (2003) used a revised form of the Ricardian approach (using hydrological proxies) to assess the way surface water affects the value of farmland and the climate sensitivity of agriculture in the United States (Benhin, 2006).

Another study by Deschênes and Greenstone (2007) measured the economic impact of climate change on US agricultural land by estimating the effect of random year-to-year variation in temperature and precipitation on agricultural profits. The preferred estimates indicate that climate change will increase annual profits by $1.3 billion in 2002 dollars

(2002$) or 4 percent. This estimate is robust to numerous specification checks and relatively precise, so large negative or positive effects are unlikely. The authors also found that the hedonic approach—which is the standard in the previous literature—to be unreliable because it produces estimates that are extremely sensitive to seemingly minor choices about control variables, sample, and weighting.

Furthermore, the Ricardian method, as a cross-section analysis, does not account for dynamic transition costs which can occur as farms move between two states. For example, if a farmer has crop failures for a year or two as he learns about a new crop, this transition cost is not reflected in the analysis. Similarly, if the farmer makes the decision to move to a new crop suddenly, the model does not capture the cost of decommissioning capital equipment prematurely (Kurukulasuriya and Mendelsohn, 2008). Likewise, the Ricardian approach fails to fully control the impact of important variables that could also explain the variation in farm incomes. Another potential drawback is the assumption of constant prices (Cline, 1996)—as cited by Deressa and Hassan, 2009—because the inclusion of price effects is problematic and the Ricardian approach is weaker for it (Mendelsohn *et al*., 1994). This introduces a bias in the analysis, overestimating benefits and underestimating damages, and vice versa. However, these problems are significant but not fatal (Mendelsohn, 2001). Therefore, the Ricardian model is the methodological approach that will be used in the present study.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

This study, which focuses on the economic impact of climate change on farmers' revenues, covers all the 35 districts of Togo. At latitudes of 6-12˚N, the climate of Togo is tropical; it is strongly influenced by the West African Monsoon. According to McSweeney *et al* (2009), the rainfall seasons of Togo are controlled by the movement of the tropical rain belt (also known as the Inter-Tropical Conversion Zone, ITCZ), which oscillates between the northern and southern tropics over the course of a year. The dominant wind direction in regions south of the ITCZ is south-westerly, blowing moist air from the Atlantic onto the continent, but the prevailing winds north of the ITCZ come from the north east, bringing hot and dusty air from the Sahara desert (known as the *Harmattan*). As the ITCZ migrates between its northernmost and southernmost positions over the course of the year, the regions between these northernmost and southernmost positions of the ITCZ experience a shift between the two opposing prevailing wind directions. This pattern is referred to as the West African Monsoon.

In northern Togo, there is a single wet season occurring between May and November, when the ITCZ is in its northern position and the prevailing wind is south-westerly, and a dry season between December and March when the *Harmattan* wind blows north-easterly. The northern and central regions receive 200-300mm per month in the peak months of the wet season (July to September).

The southern regions of Togo have two wet seasons, one from March to July, and a shorter wet season from September to November, corresponding to the northern and southern passages of the ITCZ across the region. In Togo, the arable lands span approximately 3.6 million of hectares representing 60% of the total area of the country. However, the cultivated area is estimated at 1.4 million of hectares that represent 41% of the cultivated area mentioned above or 25% of the total area of the country (Koffi-Tessio, 2013).

The part of this study about farmers' perceptions and adaptations to climate change was conducted in the Maritime, Plateaux and Savannah regions of Togo (Figure 3.1).

The Maritime and Plateaux regions are located in the southern part of Togo, while the Savannah region is at the extreme northern part of the country. The Maritime region covers an area of about 6,329 km^2 of land and has 373 people per km^2. Whereas the Plateaux region covers 17,323 km^2 and has 75 people per km^2. The Savannah region covers 8,688 km^2 of land and has 99 people per km^2. Furthermore, according to DSID (2013), 31.1% of the agricultural population of Togo are living in the Plateaux region, 20.75% in the Maritime region and 19.85% in the Savannah region.

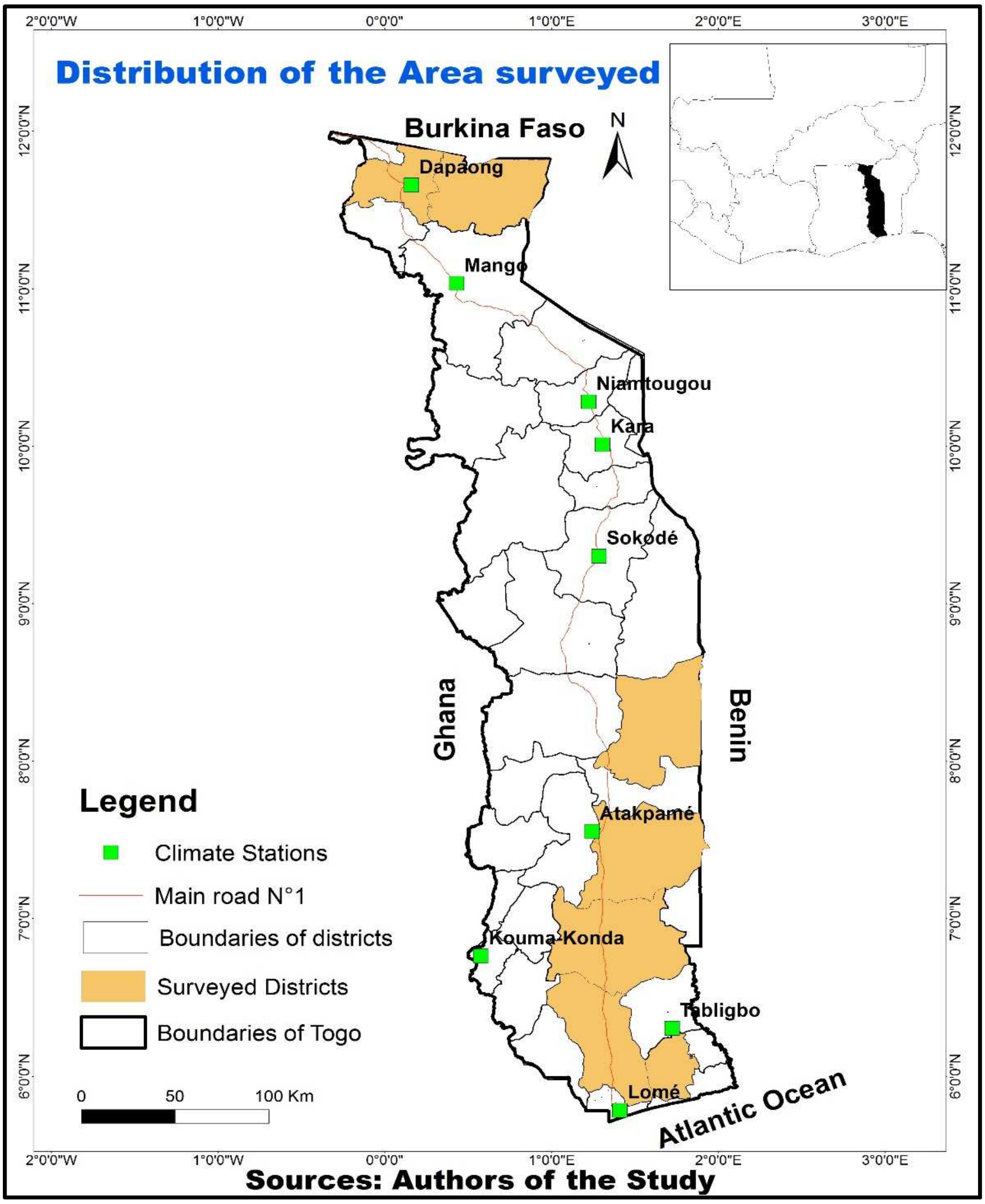

Figure 3.1. Study area

3.2 Methods

3.2.1 Economic Impact of Climate Change on the Revenue

This study will use an econometric approach known as the Ricardian method to assess economic impacts of climate change, which allows for capturing adaptations farmers make in response to climate change. The Ricardian method is successfully adopted and used to analyze the climate sensitivity of agriculture in different countries (Brazil, India, USA, Burkina Faso, Cameroon, Ghana, South Africa and Egypt), henceforth it will be the basis of our methodology.

a. Conceptual Framework

The model uses a cross-sectional approach to study agricultural production. It is based on land rent which is seen as the net revenue from the best use of land. The land rent would reflect the net productivity of farm land. Farm value (V) consequently reflects the present value of future net productivity. The principle is captured by the following equations (Mendelsohn and Dinar, 2003):

(1) $Q_i = Q_i\left(K_{ij}, E\right)$

Where, Q_i is quantity produced of goods *i*, K_{ij} is a vector of production inputs *j* used to produce Q_i and E defines a vector of exogenous environmental factors, such as temperature, precipitation, and soil, characterizing production sites. Given a set of factor prices w_j, E and Q, cost minimization gives the cost function:

(2) $C_i = C_i\,(Q_i, W, E)$

Where C_i is the cost of production of goods i and is the vector of $W(W_1, W_2, \ldots, W_n)$ factor prices. Using the cost function C_i at given market prices, profit maximization by farmers on a given site can be specified as:

(3) $Max\,\pi = [P_i Q_i - C_i(Q_i, W, E) - P_L L_i]$

Where P_L is annual cost or rent of land at that site, Li is the land in hectares, such that under perfect competition all profits in excess of normal returns to all factors (rents) are driven to zero

(4) $P_i Q_i^* - C_i^*(Q_i^*, W, E) - P_L L_i^* = 0$

If the production of goods i is the best use of the land given E, the observed market rent on the land will be equal to the annual net profits from the production of the goods. Solving for P_L from the above equation gives land rent per hectare to be equal to net revenue per hectare.

(5) $$P_L = \frac{(P_i Q_i^* - C_i^*(Q_i^*, W, E))}{L_i}$$

The present value of the stream of current and future revenues gives the land value V_L:

(6) $$V_L = \int_0^\infty P_L \, e^{-\delta t} \mathrm{dt}$$

(7) $$= \int_0^\infty \left[\frac{(P_i Q_i^* - C_i^*(Q_i^*, W, E))}{L_i} \right] e^{-\delta t} \mathrm{dt}$$

Where:

δ= discount rate and t = time and the other parameters are defined above.

The farmer is assumed to choose K to maximize net revenues, given the characteristics of the farm and market prices. The Ricardian model is based on a set of explanatory variables, such as climate, soils and socio-economic variables that affect farm value. The model uses actual observations of farm performance (Mendelsohn et al., 1994).

b. Empirical Model

The standard Ricardian model relies on a quadratic formulation of climate, consequently the net value of the land can be expressed as follows (Mendelsohn and Dinar, 2003):

(8) $$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 \mathrm{Z} + \beta_4 \mathrm{G} + \mathrm{u}$$

Where:

V= land value, F= vector of climate variables, Z= set of soil variables, G= set of socio-economic variables, β= coefficient of the variables and u = an error term

F and F^2 capture respectively linear and quadratic terms for temperature and precipitation. The introduction of quadratic terms for temperature and precipitation is to seek the likely non-linear shape of the response function between net revenue and climate. From past studies one expects that farm revenues will have U-shaped or hill shaped relationship with temperature. When the quadratic term is positive, the net revenue function is U-shaped, but if the quadratic term is negative, the function is hill shaped. For each crop, there is a known temperature where that crop grows best across the seasons, though the optimal temperature varies from crop to crop (Mendelsohn et al., 1994).

From equation (8) we can derive the marginal impact of a climate variable (f_i) on farm revenue evaluated at the mean as follows:

(9) $E\left[\frac{dV}{df_i}\right] = \mathrm{E}\left[\beta_{1,i} + 2\beta_{2,i} * f_i\right] = \beta_{1,i}$ Because $E(f_i) = 0$

The change in welfare, ΔU, resulting from a climate change from C_0 to C_1, can be measured as follows (Kurukulasuriya and Mendelsohn, 2006):

(10) $\Delta U = V(C_1) - V(C_0)$

If the change increases net income, it will be beneficial, and if it decreases net income, it will be harmful.

c. Model Specification for the Study Area

Following Mendelsohn and Dinar (2003), the empirical estimation of the Ricardian model for Togo draw from the standard model given above (Equation 8) to capture the distinctiveness of the climate in Togo. Therefore, zone dummy variables were introduced in the empirical model for Togo to capture the climate impact across regions. Some variables such as latitude, altitude, flood-prone and wetland included in the original model (Mendelsohn *et al*., 1994) were not taken into account in the present study because of lack of data. Some socio-economic variables such as household size, education attainment, access to extension services and livestock ownership which were not included in the original model accounted for the present study in order to capture farmers' adaptation to climate change. So we opted for the following functional forms:

- The model without adaptation options, including only the physical variables (temperature, rainfall, and soils) and the zone dummies:

$V_{net,ha} = \beta_0 + \beta_1 T_r + \beta_2 (T_r)^2 + \beta_3 T_d + \beta_4 (T_d)^2 + \beta_5 R_r + \beta_6 (R_r)^2 + \beta_7 R_d +$

$\beta_8 (R_d)^2 + \sum_{i=1}^{n} b_i \, Soil_i + D_z + \mathrm{u}$…………………………………………………………… (Model 1)

Where **V** is farmland net revenue, **T** and **R** are the mean temperature and the mean rainfall, respectively; while **r** represents rainy season and **d** dry season, β_i, $\mathbf{b_i}$ are the coefficients of the various variables in the model, β_0 is a constant term and u is an error term. Moreover, D_z are regional dummies (for the 5 administrative regions in Togo).

- The model with adaptation options includes the previous variables and farms characteristics and socio-economic variables.

$V_{net,ha} = \beta_0+\beta_1 T_r+\beta_2 (T_r)^2+\beta_3 T_d+a_4 (T_d)^2+a_5 R_r+\beta_6 (R_r)^2+\beta_7 R_d+$

$\beta_8 (R_d)^2 + \sum_{i=1}^{n} b_i\, Soil_i+\sum_{j=1}^{n} c_j\, Z_j+D_z+$u………………………………………… (Model 2)

Where Zj is a set of socio-economic characteristics of the farms, while $\beta_{\mathbf{i}}$, $\mathbf{b_i}$ and $\mathbf{c_j}$ are coefficients of the variables, $\beta_{\mathbf{0}}$ is a constant term and u is an error term. The independent variables include the linear and quadratic terms of temperature, rainfall and only the linear terms of soils and characteristics of the farms and socio-economic variables.

3.2.2 Farmers' Perception of Climate Change

The logit model was employed due to the nature of the decision variable; whether farmers perceived change in the temperature and/or the rainfall or not. The logit model considers the relationship between a binary dependent variable and a set of independent variables, whether binary or continuous. The logistic model is given by (Greene, 2003):

(11) $\log(P_i/(1\text{-}P_i)) = \text{Log}\ (P_i) = \beta_0+\beta_i X_i$

Where, Pi is the probability of perceiving a change in the climate and Xi an independent variables. Therefore, the parameter β_i gives the log odds of the dependent variable and β_0 is a constant.

The probability of occurrence of an event relative to non-occurrence is called odds ratio and is given by (Greene, 2003):

(12) $P_i/(1\text{-}P_i) = \exp(\beta_0+\beta_i X_i)$

3.2.3 Farmers' Adaptation to Climate Change

Given that we investigate several adaptation choices, the appropriate econometric model would, thus, be either a multinomial logit (MNL) or multinomial probit (MNP) regression model. Both models estimate the effect of explanatory variables on a dependent variable involving multiple choices with unordered response categories. In this study, therefore, an MNL specification is adopted to model climate change adaptation behaviour of farmers involving discrete dependent variables with multiple choices. The advantage of the MNL is that it permits the analysis of decisions across more than two categories, allowing the determination of choice probabilities for different categories (Madalla, 1983; Wooldridge, 2002 cited by Deressa et al, 2009).

The multinomial logit model is useful in investigating consumer choice behaviour and has become increasingly popular in marketing research. Let **C** be a set of ***n*** choices, denoted by $\{1; 2;\ldots; n\}$. A subject is present with alternatives in **C** and is asked to choose the most preferred alternative. Let $\boldsymbol{x_i}$ be a covariate vector associated with the alternative ***i***. The multinomial logit model for the choice probabilities is given by

$$(13) \quad Pr(i|C) = \frac{e^{X_i'\beta}}{\sum_{j=1}^{n} e^{X_j'\beta}}$$

Where β is a vector of unknown regression parameters.

Unbiased and consistent parameters estimates of the MNL model in equation (13) require the assumption of independence of irrelevant alternatives (IIA) to hold. The property of the logit model whereby P_j/P_k is independent of the remaining probabilities is called the **independence from irrelevant alternatives (IIA)** (Greene, 2003). Specifically, the IIA assumption requires that the likelihood of a household's using a certain adaptation measure needs to be independent of other alternative adaptive measures used by the same household. Thus, the IIA assumption involves the independence and homoscedastic disturbance terms of the adaptation model in equation (13). The validity of the IIA assumption could be tested using Hausman's specification, which is based on the fact that if a subset of the choice set is truly irrelevant, omitting it from the model altogether will not change parameter estimates systematically (Gbetibouo, 2009). Exclusion of these choices will be inefficient but will not lead to inconsistency. But if the remaining odds ratios are not truly independent from these alternatives, then the parameter estimates obtained when these choices are included will be inconsistent (Greene, 2003). The shortcoming of this technique is that all multinomial replications of a multivariate choice system have problems in interpreting the influence of explanatory variables on the original separate adaptation measures.

3.3 Data Collection and Analysis

3.3.1 Data Used for the Economic Impact Analysis

The data for the analysis were based on cross-sectional data on household and district level. These include farm household, climate and soils data.

- **Farm Household Data from 2012 Agricultural Census**

Farm household data were obtained from a survey conducted in the 35 districts of Togo in the framework of the national agricultural census (RNA) 2012/2013. The nine crops included are maize, sorghum, millet, rice, yam, cassava, potato, bean and groundnut. From this database were selected:

- Socio-economic characteristics of agricultural households (household size, gender, education level, etc.);
- Farm characteristics (cropland, type of crop, land ownership, etc.);
- Factors of production (land, agricultural input, equipment and tools etc.); and
- Socio-institutional environment of the farmer (access to subsidies, access to extension services etc)

- **Climate Data**

Climate data were collected from the National Meteorological Service. These data comprise monthly average rainfall and mean temperature from 1961 to 2013 recorded in the weather stations: Lomé and Tabligbo in Maritime region; Kouma-Konda and Atakpamé in the Plateaux region; Sokodé in the Central region; Kara and Niamtougou in the Kara region; Mango and Dapaong in the Savannah region (Figure 3.1).

The climate data at district level were not available. Indeed, climatic data have to be related to agro-economic data so that we can use them in the estimation and simulation of the Ricardian model. Therefore, it was necessary to predict the climatic conditions for each district thanks to the nearest meteorological station.

To achieve that goal, we did a spatial interpolation analysis by using Geostatistical Analyst tool in ArcGIS 10.1 software (ESRI). The Geostatistical Analyst provides two groups of interpolation techniques: deterministic and geostatistical. All methods rely on the similarity of nearby sample points to create the surface. Deterministic techniques use mathematical functions for interpolation. Geostatistics relies on both statistical and mathematical methods which can be used to create surfaces and assess the uncertainty of the predictions. Moreover, IDW (inverse distance weighted) and Spline interpolation tools are referred to as deterministic interpolation methods, because they are directly based on the surrounding measured values or on specified mathematical formulas that determine the smoothness of the resulting surface. A second family of interpolation methods consists of geostatistical methods, such as Kriging, which are based on statistical models that include autocorrelation—that is, the statistical relationships among the measured points. Because of this, geostatistical techniques not only have the capability of producing a prediction surface but also provide some measure of the certainty or accuracy of the predictions (ESRI, 2003). Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location.

There are two Kriging methods: ordinary and universal. Ordinary Kriging is the most general and widely used of the Kriging methods and is the default. It assumes the constant mean is unknown. This is a reasonable assumption unless there is a scientific reason to reject it. Universal Kriging assumes that there is an overriding trend in the data—for example, a prevailing wind—and it can be modeled by a deterministic function, a polynomial. This polynomial is subtracted from the original measured points, and the autocorrelation is modeled from the random errors. Once the model is fit to the random errors and before making a prediction, the polynomial is added back to the predictions to give meaningful results. Universal Kriging should only be used when you know there is a trend in your data and you can give a scientific justification to describe it. So in our study ordinary Kriging was used to interpolate temperature and rainfall for all the districts, where there is no meteorological station. In addition, the mathematical forms used to express autocorrelation in our study are semivariograms. The semivariogram functions quantify the assumption that things nearby tend to be more similar than things that are farther apart. Semivariograms measure the strength of statistical correlation as a function of distance (Appendices E and F).

To quantify how well the experimental semivariogram and the Kriging estimator predicts values at non data locations, I compared the parameters of the semivariogram which are the sill, nagget and range for the existing various semivariogram model. Based on these parameters, the spherical model was the one that fitted well with the temperature data set, while the exponential model was the most appropriate for the rainfall data set. In addition, the mean absolute error (MAE) was used for the same purpose and its results were in line with the previous conclusion.

- **Soil Data**

Soil data were obtained from Harmonized World Soil Database (HWSD), version 1.2 (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012) and National Institute for Agricultural Research

(ITRA). The main aim of the HWSD is to be of practical use to modellers and serve perspective studies in agro-ecological zoning, food security, climate change impacts etc. A resolution of about 1 km (30 arc seconds by 30 arc seconds) was selected. Four source databases were used to compile version 1.2 of the HWSD: the European Soil Database (ESDB), the 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database), and the Soil Map of the World. The data provided information on major and minor soils by districts in the country.

3.3.2 Data Used for Farmers' Perception and Adaptation Analysis

- **Survey Data and Sampling Procedure**

The current study is based on a cross-sectional household survey data of a total of 320 mixed crops and livestock farmers collected during the month of August 2014 in the Maritime, Plateaux and Savannah regions of Togo. The sample regions were purposely selected for this study based on a study by UNDP (2011) entitled "L'impact des changements climatiques: analyse des volets relatifs à la pauvreté au Togo". In this study, they came out with three vulnerable zones to climate change impact in Togo. These are: zone 1 (Maritime region and Plateaux region), zone 2 (Central region and Kara region) and zone 3 (Savannah region). Also, they disclosed that the zone 1 and zone 2 are more likely vulnerable to decrease in rainfall at 2025 horizon whereas, the zone 3 is concerned with an increase in temperature. Hence, in order to take into account both concerns—decrease in rainfall and increase in temperature—the zone 1 and zone 3 were chosen for the current study. Then two districts were selected the Maritime region (Zio and Vo); three from the Plateaux region (Haho, Ogou and Est-Mono) and two from the Savannah region (Tone and Kpendjal). Two peasant associations were selected from every district.

Once the peasant associations were chosen, at least 20 farmers were randomly selected from each peasant association. In addition to this, some farmers who are not members of an association were interviewed in every district. Finally, 100 farmers were interviewed in the Savannah region as well as in the Plateaux region while 120 were interviewed in the Maritime region. Besides collecting data on different socioeconomic and environmental attributes, the survey also included information on farmers' perceptions of climate change and adaptation methods. The surveyed farmers were asked questions about their observation in the patterns of temperature and rainfall over the past 20 years.

- **Meteorological Data**

Monthly rainfall and temperature data were obtained from the Togolese main Meteorological Service in Lomé. The data cover the period from January 1961 to December 2013 for all the meteorological services located within each of three regions selected for this study.

3.3.3 Description of the Variables Used in the Study

a. Variables Used for the Economic Impact Analysis

As discussed earlier, the dependent variable of the model is net farm revenue per hectare and gross revenue per hectare, while independent variables are rainfall, temperature, soil and other socio-economic characteristics.

- **Dependent Variable**

The net farm revenue was calculated for each agricultural household and is defined as being the value of the gross crop revenue minus the associated production costs. The cost elements include expenditure on transport, fertilizer, pesticide, seeds and hired labor. Other costs include farmland rent, interest paid on loans and household labour; but these were excluded from the estimation of the costs, because of the possibility of overestimation. I checked household labour by using household size as a proxy for household labour in the model, while the gross revenue per hectare is the product of total harvest and price of the crop divided by the area in hectares.

- **Independent Variables**

The explanatory variables include climatic variables, soil variables, the farms and socio-economic variables.

• Climatic Variables

These are temperature and rainfall variables, for temperature (in degrees Celsius) and rainfall (in mm/month). In Togo, the climate varies according to the southern or northern regions. Globally, the southern regions (Maritime and Plateaux) include four seasons: the long dry season from mid-November to March, the long wet season from March or April to July, the short dry season from August to September and the short wet season from September to mid-November. The central and the northern regions (Kara and Savannah) are subject to two seasons: the wet season from May to October and the dry season from November to April.

The temperature and rainfall normal were computed based on the various seasons mentioned above

• **Soil Variables**

Out of the various soils found in Togo regarding the HWSD, about five major were considered in the present study. The major soil type in Togo is Lixisols (LX): Soils with subsurface accumulation of low activity clays and high base saturation; these represent 50% of all the soils in the country, according to Soklou (2000). Other important ones are Leptosols (LP): very shallow soils over hard rock or in unconsolidated very gravelly material; Nitisols (NT): deep, dark red, brown or yellow clayey soils having a pronounced shiny, nut-shaped structure; Plinthosols (PT): wet soils with an irreversibly hardening mixture of iron, clay and quartz in the subsoil; and Vertisols (VR): dark-coloured cracking and swelling clays (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012) (Appendix VII).

• Farms Characteristics and Socio-economic Variables

Factors that explain the variability of agricultural incomes are the type of agricultural equipment used and the level of production intensification (land, work). Animal traction and tractor variables are taken into account when it comes to the level of equipment. For the production factors, we examined the effect of the total area farmed, the household size and the use of hired labour. These two last variables serve as proxy to the household labour which is discarded in calculating the net income. The expected effect of these variables is positive.

The effect of extension on net revenue was examined. Extension services promote the use of agricultural inputs (fertilizers, pesticides and improved seeds) in order to increase crop yield. The expected effect of these variables is positive. In addition, socio-economic characteristics, such as age, sex and education level of the household head were included in the model, implying that such variables do matter in agricultural productivity. For instance, age of the household is often used as a proxy variable for farm experience. The key summary statistics of all the variables used in the estimation are given in Table A.1 (page 64).

b. Variables Used for Farmers' Perception and Adaptation Analysis

Based on the information about adaptation choices in the study, the choice sets considered in the adaptation model include eight variables:

- Crop diversification
- Change in crops

- Find off-farm jobs
- Change the amount of land
- Change planting dates
- Plant short season variety
- Other
- No adaptation

Based on the review of literature on adoption of new technologies and adaptation studies, a range of household and farm characteristics, institutional factors, and other factors that describe local conditions are hypothesized to influence farmers' adaptation choice in the study area.

Table 3.1 presents the variables hypothesized to determine adaptation behaviour, a brief description of each variable, its value, and expected sign in relation to adoption of new technologies.

- **Household Characteristics**

The expected result of age is an empirical question. We may find that age negatively influences the decision to adopt new technologies. It may be that older farmers are more risk-averse and less likely to be flexible than younger farmers and thus have a lesser likelihood of adopting new technologies. In another case, age positively influences the decision to adopt. It could also be that older farmers have more experience in farming and are better able to assess the characteristics of modern technology than younger farmers, and hence a higher probability of adopting the practice. Gbetibouo (2009), Ajao and Ogunniyi (2011) and Fosu-Mensah et al (2010) found that gender did not have a significant impact on the probability of choosing any adaptation technique.

Education is expected to increase one's ability to receive, decode, and understand information relevant to making innovative decisions (Wozniak, 1984, cited by Gbetibouo, 2009), therefore to increase the probability of adopting new technologies.

Gender of the household head is hypothesized to influence the decision to adopt changes. A number of studies in Africa have shown that women have lesser access to critical resources (land and labour), which often undermines their ability to carry out labour-intensive agricultural innovations (De Groote and Coulibaly 1998, Quisumbing et al. 1995, cited by Gbetibouo, 2009). However, a recent study by Nhemachena and Hassan (2007), based on

Southern Africa, finds that female-headed households are more likely to take up climate change adaptation methods.

Farming experience increases the probability of uptake of all adaptation options because experienced farmers have better knowledge and information on changes in climatic conditions and crop (Nhemachena and Hassan, 2007).

- **Institutional Factors**

Agricultural extension enhances the efficiency of making adoption decisions. In the world of less than-perfect information, the introduction of new technologies creates a demand for information useful in deciding on adopting new technologies (Wozniak, 1984, cited by Gbetibouo, 2009). In the present study, access to extension services is hypothesized to positively affect adoption of adaptation measures to climate change. Furthermore, in this specific case of climate change adaptation, access to climate information may increase the likelihood of uptake of adaptation techniques.

As any fixed investment requires the use of owned or borrowed capital, access to credit commonly is hypothesized to have a positive effect on adaptation behaviour to climate change. Similarly, land tenure is hypothesized to contribute positively to adaptation to climate change, because landowners tend to adopt new technologies more frequently than tenants. In fact, the tenants are unsecured regarding the continuation of their activities on the same land. Consequently, they are reluctant to undertake long term adaptation measures on a rented land. Belonging to farmers' association is a plus regarding access to information on climate and extension services. Therefore, membership in farmers' association is also hypothesized to have a positive effect on adaptation to climate change.

- **Farm Characteristics**

Farm size is hypothesized in the present study to influence positively adaptation to climate change, because farmers who have larger land under cultivation tend to adopt new technology easily than small scale farmers. With respect to soil fertility, farmers' perception of their lands to be infertile may be a first step in the adaptation process. They may, therefore, be more likely to adopt any adaptation techniques that will help improve their productivity.

- **Other Factors**

Other factors such as zone dummy variables for the three regions of the study area were included in order to account for any specific institutional arrangements having favoured farmers to adapt to climate change.

Table 3.1. Description of variables hypothesized to affect adaptation decision by farmers

VARIABLES	DESCRIPTION	VALUE	Expected sign
	Household characteristics		
Age	Age of the farmer	years	Cannot be signed a priori (+ or -)
Gender	Gender of the farmer	1= male, 0= female	Cannot be signed a priori (+ or -)
Education level	Number of years of formal schooling attained by the farmer	years	Positive
Farming experience	Number of years of farming experience of the farmer	years	Positive
	Farm characteristics		
Farm size	Number of hectares of land cultivated by the farmer	Hectarage	Positive
Soil fertility	Farmer's own perception of the fertility level of his/her land	1= fertile soil, 0= infertile soil	Positive
	Institutional factors		
Access to extension	If the farmer has access to extension services	1= yes, 0= no	Positive
Access to climate information	If the farmer gets information about weather, climate from any source ─ extension offers, TV, radio, etc ─	1= yes, 0= no	Positive
Access to credit	If the farmer has access to credit from any sources	1= yes, 0= no	Positive
Land tenure	If land used is owned or rented/shared cropped, etc	1= owned, 0= otherwise	Positive
Farmers' group membership	If the farmer is a member of a farmers' group	1= yes, 0= no	Positive
	Other factors		
Plateaux region	If the farmer farms in the Plateaux region	1= yes, 0= no	Cannot be signed a priori (+ or -)
Savannah region	If the farmer farms in the Savannah region	1= yes, 0= no	Cannot be signed a priori (+ or -)
Maritime region	If the farmer farms in the Maritime region	1= yes, 0= no	Cannot be signed a priori (+ or -)

3.3.4 Specific Climate Change Scenarios for Togo

In the past, several sets of scenarios have been used for better comparisons between various studies as well as easier communication of model results, including the IS92 scenarios

(Leggett et al., 1992) and, after that, the scenarios from the Special Report on Emission Scenarios (SRES) (Nakicenovic et al., 2000 as cited by Vuuren et al., 2011). As pointed out by Moss et al. (2010), the research community currently needs new scenarios. First, more detailed information is needed for running the current generation of climate models than that provided by any previous scenario sets. Second, there is an increasing interest in scenarios that explicitly explore the impact of different climate policies in addition to the no-climate-policy scenarios explored so far (e.g. SRES). Such scenarios would allow evaluating the "costs" and "benefits" of long-term climate goals. Finally, there is also an increasing interest in exploring the role of adaptation in more detail. The need for new scenarios prompted the Intergovernmental Panel on Climate Change (IPCC) to request the scientific communities to develop a new set of scenarios to facilitate future assessment of climate change (IPCC, 2007). The scientific communities subsequently designed a process of three phases (Moss et al., 2010):

- Development of a scenario set containing emission, concentration and land-use trajectories referred to as "representative concentration pathways" (RCPs);
- A parallel development phase with climate model runs and development of new socio-economic scenarios;
- A final integration and dissemination phase.

The main purpose of the first phase (development of the RCPs) is to provide information on possible development trajectories for the main forcing agents of climate change, consistent with current scenario literature allowing subsequent analysis by both Climate models (CMs) and Integrated Assessment Models (IAMs). Climate modellers will use the time series of future concentrations and emissions of greenhouse gases and air pollutants and land-use change from the four RCPs in order to conduct new climate model experiments and produce new climate scenarios as part of the parallel phase. At the same time, IAMs will explore a range of different technological, socio-economic and policy futures that could lead to a particular concentration pathway and magnitude of climate change. The development of the RCPs in the first phase thus allows climate modellers to proceed with experiments in parallel to the development of emission and socio-economic scenarios, expediting the overall scenario development process (Moss et al., 2010).

A careful selection process was used to identify the RCPs, using criteria that reflected the needs of both climate scenario developers and users. Two important characteristics of

RCPs are reflected in their names. The word “representative” signifies that each of the RCPs represents a larger set of scenarios in the literature. In fact, as a set, the RCPs should be compatible with the full range of emissions scenarios available in the current scientific literature, with and without climate policy. The words “concentration pathway” are meant to emphasize that these RCPs are not the final new, fully integrated scenarios (i.e. they are not a complete package of socio-economic, emission and climate projections), but instead are internally consistent sets of projections of the components of radiative forcing that are used in subsequent phases. The use of the word “concentration” instead of “emissions” also emphasizes that concentrations are used as the primary products of the RCPs, designed as input to climate models. Coupled carbon-cycle climate models can then as well calculate associated emission levels (which can be compared to the original emissions of the IAMs) (Hibbard *et al*. 2007). In total, a set of four pathways were produced that lead to radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m^2, by the end of the century. Each of the RCPs covers the period from 1850 to 2100, and extensions have been formulated for the period thereafter (up to 2300) (Vuuren *et al*., 2011).

Table 3.2. Main characteristics of the four RCPs

Name	**Radiative forcing**	**Concentration of GHGs (p.p.m.)**	**Pathway***	**Model providing RCP**
RCP8.5	>8.5Wm^{-2} in 2100	>1,370 CO_2-equiv. in 2100	Rising	MESSAGE
RCP6.0	~6Wm^{-2} at stabilization after 2100	~850 CO_2-equiv. (at stabilization after 2100)	Stabilization without overshoot	AIM
RCP4.5	~4.5Wm^{-2} at stabilization after 2100	~650 CO_2-equiv. (at stabilization after 2100)	Stabilization without overshoot	GCAM
RCP2.6	Peak at~3Wm^{-2} Before 2100 and then declines	Peak at~490 CO_2-equiv. before 2100 and then declines	Peak and decline	IMAGE

*MESSAGE, Model for Energy Supply Strategy Alternatives and their General Environmental Impact, International Institute for Applied Systems Analysis, Austria; AIM, Asia-Pacific Integrated Model, National Institute for Environmental Studies, Japan; GCAM, Global Change Assessment Model, Pacific Northwest National Laboratory, USA (previously referred to as MiniCAM); IMAGE, Integrated Model to Assess the Global Environment, Netherlands Environmental Assessment Agency, The Netherlands. **Source:** Moss et al, 2010. The value of radiative forcing for 2011 is 2.84 Wm^{-2}

In this study I chose RCP8.5 scenarios to compute the provisional impact of change in temperature and rainfall on Togolese farmers' revenues. The reason why I chose RCP8.5 is that compared to the total set of Representative Concentration Pathways (RCPs), RCP8.5 corresponds to the pathway with the highest greenhouse gas emissions (Riahi k. *et al*., 2011). Additionally, it is meaningful to make a prevision based on the worst cases. Based on RCP8.5 anomaly from 6 GCM-ESMs' (BCC-CSM1, CSIRO-Mk3-6-0, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5, NorESM1-M) Ensemble mean with 1981-2005 as baseline downscaled to West Africa, the near surface air temperature will increase by 1^oC and 2^oC at horizon 2025 and 2050, respectively in Togo. As regards to rainfall, there will be a decrease at 2.5% and 10% rate for horizon 2025 and 2050 respectively in Togo (Salack *et al*., 2013). (Appendices C and D)

3.3.5 Estimation Procedure

Regarding the economic impact analysis, Excel, SPSS 20 and Stata 11.2 software were used to analyse the data. Different stages of the estimations were undertaken. At the first stage, I integrated climatic variables, soils variables and zone dummies. By doing so, I defined the model without adaptation that relies only on physical factors (climate and soils).

At the second stage, we integrated into the first model characteristics of the farms and socio-economic variables (household size, farmland, use of hired labour, livestock ownership etc.) and the environment in which they evolve (access to extension service, etc.). These have enabled me to take farmers' adaptations into consideration and to assess their effects on the agricultural income. This second stage will lead us to the model with adaptation options.

The impact of outliers, multicollinearity among explanatory variables, endogeneity and heteroscedasticity in the error terms are major econometric problems often faced with cross-sectional data (Benhin, 2006). Given that these econometric issues will likely affect the robustness of the regression results, some tests have been done and remedies were undertaken to correct these problems. White's general heteroscedasticity test was performed for heteroscedasticity; correlation analysis was performed to examine the association between the independent variables and to check for multi-collinearity among them. Also, Variance Inflation Factor (VIF) for association among continuous explanatory variables and contingency coefficients for dummy variables were used for the same purpose. I checked for multicollinearity by dropping the most problematic variables, especially in cases of detecting strong collinearity and where the explanatory variables do not improve on the model and are also insignificant. To correct for heteroscedasticity I estimated a robust regression instead of an ordinary regression. Hausman test was performed on the hypothesized variables to endogenous. Especially, this test was performed on education level.

Regarding farmers' perceptions and adaptation to climate change, correlation analysis was performed to assess the association between the determinant factors and to check for multi-collinearity among them. Also, Variance Inflation Factor (VIF) for association among continuous explanatory variables and contingency coefficients for dummy variables were used for the same purpose, while descriptive statistics and binary logistic regression model were used to analyse the determinant factors of farmers' perceptions of climate change and variability in Togo. Finally, a multinomial logit (MNL) model was used to assess the determinant factors of farmers' adaptation choices to climate change.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Economic Impact Analysis

4.1.1 Regression Models

The net revenue and gross revenue were regressed on climate, soil, and socioeconomic variables to estimate the best-value function across different districts. There are 1,337 cross-sectional observations. In order to give a sense of the importance of the nonfarm variables in the model, we began with a model that contains only climate variable and soil (Table 4.1), then the one with socio-economic variables (Table 4.2).

Regarding model validation, I have used the Fisher-Snedecor test to validate the total significance of the models and the Student test for the individual significance of each coefficient. The Fisher-Snedecor test shows that the four regressions are all significant at the 1% level making the function to be well behaved. However, the coefficient of determination (R^2) shows that the models explain only between 09 and 11%, 13 and 46% of the total variation, respectively in the net and gross revenue. Whatever the model regressions estimated, a large part of the variation in the agricultural income remains unexplained by the variables taken into account. However, these models remain satisfactory regarding the results obtained in the framework of similar studies (Gbetibouo G. and Hassan R., 2005; Kurukulasuriya et al., 2006; Ouedraogo and Dembele, 2006).

Tables 4.1&4.2 present the results of the estimated models. The results show that the signs of seasonal climatic variables are the same for all the estimated models, except rainy season temperature. The sign of quadratic terms is opposite to the sign of linear terms for the temperature and the precipitation. The relationship between net revenue or gross revenue and temperature or precipitation is therefore non-linear. Similarly, the squared terms for most of the climate variables are significant, implying that the observed relationships are non-linear. Thus, the first specific objective of our study is attained. This means that temperature or precipitation affects the net and gross revenues positively up to a certain level, above which it causes damage to the crops. However, some of the squared terms are positive, especially for precipitation, implying that there is a minimum productive level of precipitation and that either more or less precipitation will increase net revenue or gross revenue. The negative quadratic coefficient implies that there is an optimal level of a climatic variable from which the value function decreases in both direction.

Table 4.1. Model without adaptation (soil, climate and zones variables)

VARIABLES	COEFFICIENTS	
	Net Revenues (per hectare)	**Gross Revenues (per hectare)**
Rainy season precipitation	87.78 (3.14)**	13.63 (0.47)
Rainy season precipitation squared	-0.28 (3.07)**	-0.04 (0.42)
Dry season precipitation	-40.82 (3.82)**	-55.18 (4.13)**
Dry season precipitation squared	0.32 (4.04)**	0.36 (3.93)**
Rainy season temperature	-3,977.09 (1.12)	4,312.82 (1.18)
Rainy season temperature squared	67.34 (1.00)	-94.19 (1.36)
Dry season temperature	9,707.55 (2.90)**	4,420.72 (1.34)
Dry season temperature squared	-171.22 (2.81)**	-73.14 (1.22)
Nitisols (NT)	49.205 (0.55)	-78.49 (0.85)
Leptosols (LP)	-3.09 (0.03)	-70.26 (0.60)
Vertisols (VR)	-104.53 (0.98)	-173.42 (1.54)
Plinthosols (PT)	290.08 (1.52)	501.6 (2.28)*
Plateaux region zone	-185.56 (1.18)	88.64 (0.53)
Central region zone	96.51 (0.50)	244.19 (1.27)
Kara region zone	-671.77 (2.40)*	-1262.9 (3.44)**
Savannah region zone	-1,107.08 (2.96)**	-1,686.19 (3.68)**
Constant	-84,107.61 (4.47)**	-112,470.5 (5.66)**
R^2	0.09	0.13
N	1,337	1,337

* p<0.05; ** p<0.01

Values in parenthesis are robust t-statistics.

The regressions show that high rainy season temperatures are harmful to crop production while high dry season temperatures are beneficial to it. This is because rainy season is the planting period followed by formative crop growth, while dry season is the period for ripening and maturing of crops. High rainy season temperatures would therefore slow down or destroy crop growth, while higher dry season temperatures are crucial for ripening and harvesting. The negative coefficient for the quadratic term suggests, however, that excess dry season temperatures would be harmful for crop productivity. Based on the sign of their coefficients, rainy season temperatures exhibit a U-shaped relationship with net revenue and dry season temperatures a hill-shaped one. Therefore, the results further show that climate exhibits a non-linear relationship with net revenue or gross revenue, which is consistent with the available literature (Mendelsohn et al. 1994, 2003; Kurukulasuriya and Mendelsohn 2006).

The effects of Leptosols and Vertisols are negative for both models, which can be explained by the low fertility level and low water retention capacity of these types soil in Togo. Regarding the relevance of various soil types, Leptosols and Plinthosols affected gross revenue significantly as shown in the regression of the model with adaptation. In addition, Lixisols was used as reference type of soil to which the comparisons were made. The results showed that the gross revenue from Plinthosols on average for both models is higher than the ones from other types of soil. Moreover, the net and gross revenues from Vertisols and Nitisols were not significantly different from the ones from Lixisols.

Contrary to expectation, farm area had positive effects on farmers' revenue, because increasing the area under crops does not necessarily help increase the yield generally. This is due to the fact that in Togo, where agriculture is extensive, most farmers do not have the capacity to manage large areas. This result is contradicts what Ouedraogo (2006) found and which is confirmed by Eid et al (2006). However, this strategy helps increase the total quantity of produce harvested. This explained why the farm area had positive and significant effect on farmers' gross revenue per hectare. As expected a priori, livestock ownership was found to be positively and significantly related to net and gross revenues because manure improves soil productivity and the animals provide the farmer with transport. This finding is contrary to what Ouedraogo (2006) found.

The regressions showed that the household size was negatively related to net and gross revenues, because there are many dependent and unproductive people in rural area in Togo (such as children, and the elderly, and sick). These results mirror Deressa's (2006) findings. As expected, education level and access to extension services turned out positive, supporting the fact that increased access to extension services and education are associated with improved farming information.

The regressions equally showed that population density is negatively and significantly related to net and gross revenues. In other words, the denser the district the lower the net or gross revenues. This could be explained by the fact that in order to meet higher local demands for food, farmers increase area under crops and they do not have the capacity to manage large areas. As a result, the yield will generally decrease. These results are conflict with to Mendelsohn et al's (1994) findings. Moreover, the variable sex affects negatively and significantly the net and gross revenues. These results seem to be a bit surprising because men have more capacities than women in terms of agricultural activities. This is opposite to what Thapa and Joshi (2010) found in Nepal. Furthermore, as expected, age is positively and significantly correlated with net revenue. The older the more experienced are the farmers in their activities. This result is similar to Thapa and Joshi's (2010) findings. Marital status is not significant at any required level; this variable has no impact on net or gross revenues. As for zone dummy variables, the Maritime region was used as reference region to which the comparisons were made. The results showed that Kara and Savannah regions were significant with negative sign. The import is that on average the net and the gross revenues are lower than the ones in the Maritime region. Whereas the net and gross revenues in Central and Plateaux regions were not significantly different from the ones in the Maritime region. This can be explained by the fact that farmers in the Maritime, Plateaux and Central regions suffer less form the harsh climatic conditions than those in the other regions of Togo. In conclusion, education attainment, livestock ownership, age of head of household and population density and most climate variables explain significantly smallholder farmers' crop production-based revenue in Togo. Thus, the second specific objective of our study is met.

Table 4.2. Model with adaptation (including socio-economic variables)

VARIABLES	COEFFICIENTS	
	Net Revenues (per hectare)	Gross Revenues per hectare)
Rainy season precipitation	36.84 (1.23)	-45.83 (-1.96)**
Rainy season precipitation squared	-0.14 (-1.44)	0.12 (1.63)
Dry season precipitation	-58.42 (-3.22)***	-47.05 (-2.33)**
Dry season precipitation squared	0.49 (3.84)***	0.33 (2.50)**
Rainy season temperature	-5,079 (-1.40)	4,436 (1.90)*
Rainy season temperature squared	83.01(1.21)	-92.87 (-2.07)**
Dry season temperature	12,378 (3.38)***	1,022 (0.50)
Dry season temperature squared	-217.7 (-3.27)***	-15.62 (-0.49)
Nitisols (NT)	114.4 (1.23)	-5.47 (-0.08)
Leptosols (LP)	-176.4 (-1.32)	-207.1 (-2.44)**
Vertisols (VR)	-113.4 (-1.04)	-64.79 (-0.88)
Plinthosols (PT)	318.0 (1.67)*	175.3 (1.79)*
Sex of household head	-97.01 (-1.80)*	-92.76 (-1.81)*
Age of household head	3.13 (1.88)*	-0.24 (-0.19)
Marital status of household head	-47.24 (-0.50)	72.38 (1.07)
Size of household	-4.45 (-0.69)	-3.14 (-0.57)
Education level of household head	33.34 (1.87)*	24.20 (1.69)*
Livestock ownership	90.47 (1.89)*	74.71 (2.36)**
Access to extension services	7.63 (0.14)	20.65 (0.38)
Population density	-5.62 (-4.98)***	-2.98 (-4.17)***
Population density squared	0.01 (4.35)***	0.003 (2.30)**
Crop land area	22.43 (1.29)	454.3 (8.137)***
Plateaux region zone	-231.2 (-1.35)	-11.40 (-0.08)
Central region zone	56.01 (0.28)	87.75 (0.73)
Kara region zone	-772.5 (-2.70)***	-648.1 (-2.27)**
Savannah region zone	-920.3 (-2.45)**	-699.4 (-2.18)**
Constant	-99,096 (-5.19)***	-62,293 (-3.75)***
R^2	0.11	0.46
N	1,337	1,337

* p<0.05; ** p<0.01

Values in parenthesis are robust t-statistics.

4.1.2 Marginal Impacts of Climate on Agricultural Revenue and Elasticity

The marginal impact analysis was conducted to assess the effect of an infinitesimal change in temperature and rainfall in Togo farming. The Table 4.3 showed the estimated marginal impacts of temperature and rainfall on the net and gross revenue. The marginal impacts of the temperature was calculated on the basis of the average temperature of the sample in the rainy season and in the dry season, whereas the marginal impacts of the rainfall were calculated on the basis of the average annual rainfall of the sample in the rainy season and in the dry season. In order to allow easy comparison of marginal impacts with similar studies undertaken in other countries, the values were converted from FCFA to 2014 US$ using exchange rate of 485 FCFA/US$.

In the model without adaptation, the net revenue per hectare went up at an average of US$3.55 per 1mm increase in rainfall in rainy season. This increase in net revenue is similar to what Ouedraogo (2006) found in Burkina Faso, while the gross revenue will increase by US$1.05/ha on average if rainfall increases by 1mm for the same model. The import is that with slightly higher temperature and available precipitation (soil moisture level), crop germination is enhanced. Surprisingly, 1mm increase in rainfall in rainy season was not auguring well for crop farming regarding the model with adaptation in Togo. This is due to the already high level of rainfall in the country during this season, as any increasing rainfall further results in flooding and damage to field crops. Furthermore, the results showed that marginally increasing rainfall during the dry season reduces the net revenue and the gross revenue by US$7.08 and US$18.42 without adaptation, respectively, while the decrease will be US$9.27 and US$14.09 of the net revenue and the gross revenue, respectively for the model with adaptation. When adaption measures are taken into account, the decreases are less than the case without adaptation measures for net revenue. These results are true because slight increasing precipitation with the already dry season may encourage diseases and insect pests. In addition, it is due to the fact that crops reduce water requirement during the harvesting season and more rainfall damages crops and may reinitiate growth during this season. These results are in consistency with Deressa (2006) in Ethiopia.

On the other hand, if the average temperatures increase by 1°C, the net revenue and the gross revenue will drop by US$340.33 and US$505.25 for the model without adaptation in rainy season, respectively.

Table 4.3. Marginal impact of climate on farmers' net and gross revenues in Togo

		Model Without Adaptation		Model With Adaptation	
		Net Revenues (per hectare)	**Gross Revenues (per hectare)**	**Net Revenue (per hectare)**	**Gross Revenues (per hectare)**
Rainfall	**Rainy season**	3.55	1.05	-4.35	-8.44
		(26.10)**	(2.7043)	(-10.55)	(-20.25)**
	Dry season	-7.08	-18.42	-9.27	-14.09
		(-3.94)**	(-3.56)**	(-5.55)***	(-6.44)**
Temperature	**Rainy season**	-340.33	-505.25	-652.67	-365.59
		(-207.22)	(149.88)	(-244.09)	(-355.67)**
	Dry season	333.14	419.03	490.16	174.29
		(520.91)**	(158.22)	(-638.67)***	(-49.47)

** Significant at 5% level ***Significant at 1% level
( ) number in bracket represents the elasticity of climate variables.

The inclusion of adaptation-related variables has rather aggravated the negative effects of increased temperature because the falls in the net revenue increased from the latter to US$652.67. This indicates that though the adaptation related variables are important in helping to control adverse climate effects, if they are not properly implemented they may rather aggravate the problem. And one important variable to mention is extension services, which, if not properly undertaken, may worsen the problem. Then, the third specific objective of our study is achieved.

Regarding the dry season, marginally increasing temperature would lead to an increase in the net revenue and gross revenue, respectively for both models. The import is that during dry season, a higher temperature is beneficial for harvesting. It is important that crops have finished their growth processes by dry season, and a higher temperature quickly dries up the crops and facilitates harvesting. Moreover, this means that the farmers who take into account adaptation measures are less vulnerable to the effects of climatic changes, because they integrate the climatic risks better and take enough precautions to protect their revenues.

With respect to the elasticity of the climatic variables, the results showed that a 1% increase in rainfall would lead to a 26.10 % and 2.70 % increase in the net revenue and gross revenue in the model without adaptation, respectively, while a similar change in rainfall would lead to only 10.55 % and 20.25 % fall in the net revenue and gross revenue in the model with adaptation, respectively. In dry season, using the model without adaptation, gross revenue is elastic (-3.56). Similarly, the net revenue is elastic (-3.94) for the same model. Concerning the temperature, the net revenue and the gross revenue for both models are highly elastic. These results show that higher temperatures will not augur well for productivity (elasticity is negative) and are consistent with Kurukulasuriya and Mendelsohn (2006): global warming is likely to have devastating effects on agriculture, unless farmers take adaptation measures to counter the impact of climate change. In addition, these results confirm the one found by Kabubo-Mariara and Karanja (2006) in Kenya for similar a study.

Therefore, the policy lesson for adaptation is to take advantage of the positive effects of climate change while reducing the negative ones. In the Table 4.3, one would therefore expect that including effective adaptation-related variables (socio-economic variables) will increase the magnitude of the relationship between climate variables and crop revenues for positive values while reducing the negative values. This seems to be true for only dry season, which implies that for the country as whole, adaptation variables may help reduce the negative effects and take advantage of the positive effects of high temperatures and marginally increase in rainfall.

4.1.3 Forecasts of Climate Impacts on Agriculture in Togo

To estimate the impact of climate change on the agricultural income, we have made simulations based on scenarios specific to Togo as previously discussed in this paper. We then examined the consequences of these climate change scenarios on net and gross revenues in 2025 and 2050, using the estimated model in tables 4.1 and 4.2. This is because the prediction relates mainly to climate variables and not the other variables in the model as they stand for the interest ones. Based on the results of the models run for the specific scenarios of Togo (Representative Concentration Pathway (RCP) 8.5) released by IPCC in 2013, we considered an increased temperatures of 1 °C in 2025 and 2°C in 2050 and a fall in rainfall of 2.5% in 2025 and 10% in 2050 (Salack *et al*., 2013). (Appendices C and D)

Table 4.4. Impacts from climate scenarios on farmers' net and gross revenues in Togo

Scenarios	Model Without Adaptation		Model With Adaptation	
	Net Revenues (per hectare)	Gross Revenues (per hectare)	Net Revenues (per hectare)	Gross Revenues (per hectare)
Temperature warming (1 °C)	-179.25 (-19.63)	-462.90 (-37.78)	-339.41 (-32.25)	-453.05 (-117.07)
Temperature warming (2°C)	-566.27 (-62.02)	-126.46 (-102.86)	-945.09 (-89.81)	-112.69 (-89.59)
Rainfall decreasing (2.5%)	-7.44 (-0.82)	18.02 (1.47)	27.28 (2.59)	54.40 (14.05)
Rainfall decreasing (10%)	-71.65 (-7.85)	71.83 (5.86)	95.28 (9.05)	245.34 (63.39)
Temperature warming (1 °C) and Rainfall decreasing (2.5%)	-186.69 (-20.45)	-444.88 (-36.31)	-312.13 (-29.66)	-398.64 (-103.01)
Temperature warming (2°C) and Rainfall decreasing (10%)	-637.91 (-69.87)	-118.63 (-97.00)	-849.82 (-80.75)	-875.36 (-226.19)

( ) Number in bracket represents the Percentage Changes

As it is obvious from the table 4.4, the results indicate that an increase in temperature of 1°C will reduce agricultural net revenue and gross revenue by US$179.25 and US$462.90 for the model without adaptation, respectively. A similar change in the temperature would lead to a drop in net revenue and gross revenue by US$339.41 and US$453.05 for the model with adaptation, respectively. Similarly, a loss of US$566.27 and US$126.46 in net revenue and gross revenue respectively in the model without adaptation will be expected with a 2°C increase in temperature in Togo. In other words, 1°C increase in temperature will lead to a decrease by 19.63% and 37.78% in 2025 in net revenue and gross revenue respectively without adaptation, while a loss of 62.02% and 102.86% in 2050 in net revenue and gross revenue respectively in the model without adaptation will be expected. In 2050, the introduction of adaptation-related variables in the model will reduce the fall to 89.59% in the gross revenue. These results corroborate Kurukulasuriya and Mendelsohn's (2006) findings:

global warming is likely to have devastating effects on agriculture, unless farmers take adaptation measures to counter the impact of climate change.

With respect to rainfall, an increase in the rainfall by 2.5% in 2025 will lead to 0.82% fall in the net revenue and a gain of 1.47% in the gross revenue. While in the same year, the introduction of adaptation-related variables will lead to a gain of 2.59% and 4.97% in the net revenue and gross revenue, respectively. The import is that farmers have undertaken adaptation measures to deal with harsh climatic conditions in order to improve their incomes. Moreover, similar results were found in 2050, where a 7.85% fall in the net revenue and 5.86% gain in the gross revenue were expected with 10% increase in the rainfall. In the same year and with a similar change in the rainfall, 9.05% and 63.39% gain in the net revenue and gross revenue were expected for the model with adaptation, respectively.

Furthermore, the study examined the total effects of simultaneously changing both temperature and precipitation on the net revenue and the gross revenue (last two rows in table 4.4). The results showed harmful effects on the net revenue and the gross revenue for all the two models considered in this study. The predicted impact of temperature and rainfall on farmers' revenue been determined above, the fourth specific objective of our study is met.

4.2 Perception Analysis

4.2.1 Comparison between Farmers' Perceptions of Changes in Climate and Meteorological Stations' Recorded Data

In order to assess farmers' perceptions of climate change and variability, we first look at how climate data recorded at meteorological stations in the study area evolved (linear trends and variability) and how farmers perceived these changes. In addition, tests were undertaken for linear trend in annual means of temperature and total annual rainfall. Descriptive statistics based on summary counts of the questionnaire structure are used to provide insights into producers' perceptions of climate change and variability. In the literature several studies have undertaken similar type of analysis. For instance, study by Maddison (2006), using data for over 9,500 farmers from eleven African countries, compared the probability that the climate has changed, as revealed by an analysis of the statistical record, with the proportion of individuals who believe that such a change has, in fact, occurred to assess farmers' perceptions of climatic change. Gbetibouo (2009) examined how farmers' perceptions correspond with climate data recorded at meteorological stations in the Limpopo River Basin and analysed farmers' adaptation responses to climate change and variability. They concluded that farmers' perceptions of climate change are in line with the climatic data records. Another study by Fosu-Mensah et al. (2010) assessed farmers' perception of changes in temperature and rainfall in the Sekyedumase district in Ghana. They observed that more than 80 % of farmers interviewed perceived an increasing temperature and a decreasing precipitation. In addition, they concluded that these results are consistent with the trend analysis of historical climate data of Sekyedumase district especially on temperature.

a. Temperature Changes

Across the three regions, about 85% of the farmers interviewed perceived changes in temperature. In the Maritime region, this percentage is 82.2, while in the Plateaux region it is 68.3 and 64 in Savannah region. About 72% of the farmers perceived increases in temperature, while only 12.85% noticed the contrary, a decrease in temperature. However, 9.72% of the farmers did not perceive any change in temperature (Figure 4.3).

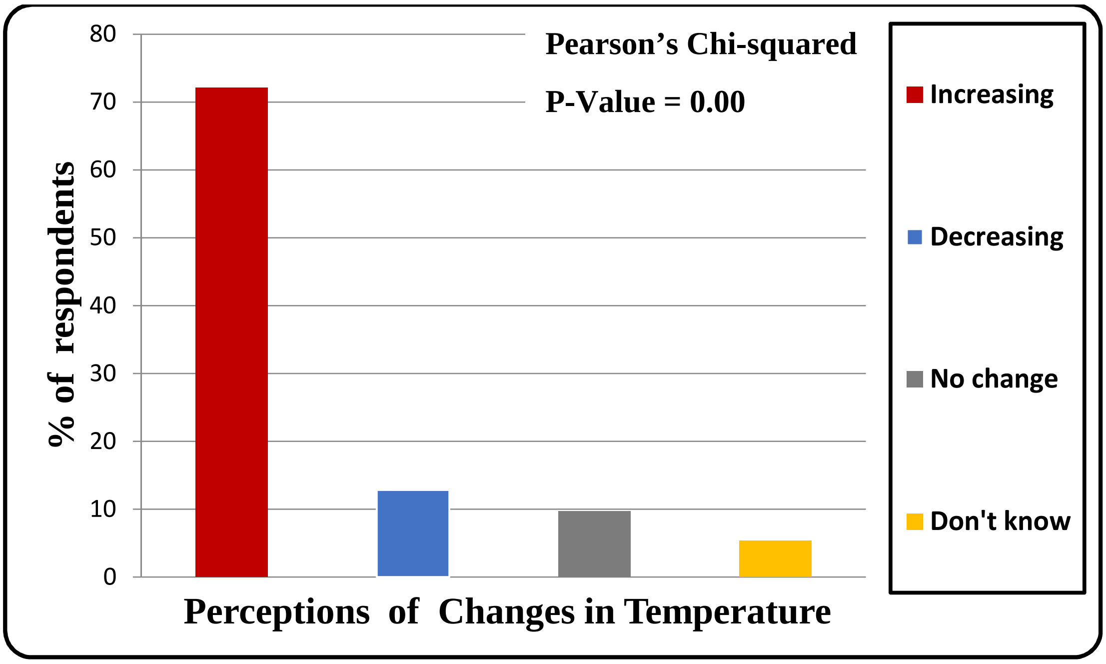

Figure 4.1. Farmers' perceptions of changes in temperature

The statistical record of temperature data from the three regions between 1961 and 2013 shows an increasing trends which are all significant at 1% level. In 53 years, the temperature has risen by 1.7 degree Celsius in the Maritime region, 0.65 degree Celsius in the Plateaux region and 1.5 degree Celsius in the Savannah region (Table 4.5 and Figure 4.4). Thus, farmers' perceptions appear to be in accordance with the statistical record in the three regions. So, smallholder farmers in the aforementioned regions are well aware about change in the temperature.

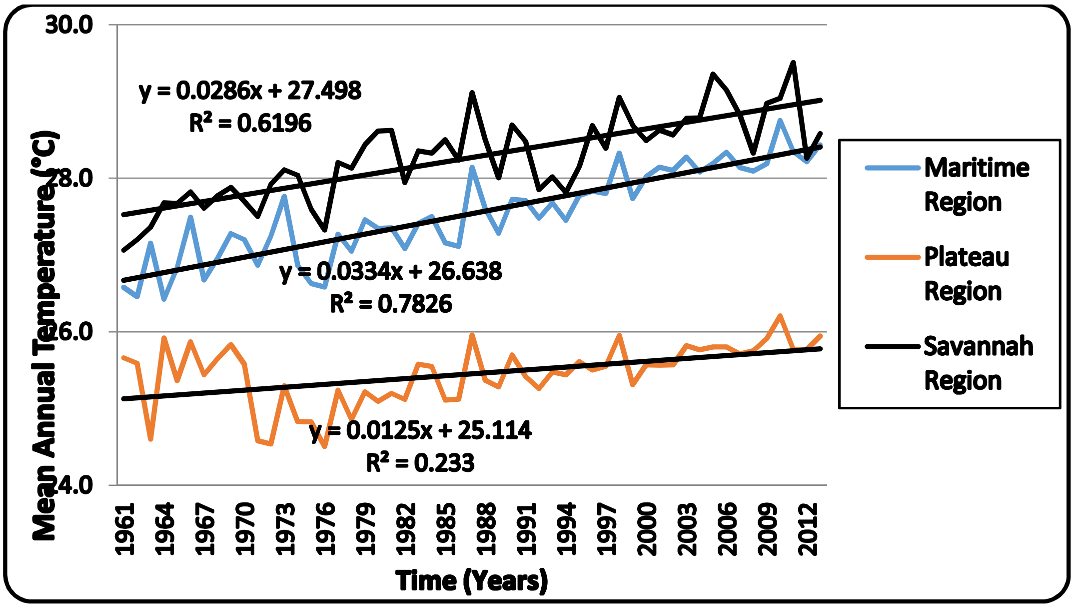

Figure 4.2. Linear trend of temperature data: 1961–2013

Table 4.5. Analysis of Temperature Data from 1961 to 2013

Yearly Temperature	**Maritime Region**	**Plateaux Region**	**Savannah Region**
Mean (^{0}C)	27.54	25.45	28.27
Standard deviation (^{0}C)	0.574	0.405	0.560
Minimum temperature (^{0}C)	26.4	24.5	27.1
Maximum temperature (^{0}C)	28.8	26.2	29.5
Trend (^{0}C/year)	0.0334***	0.0125***	0.0286***
Correlation	0.8813	0.4882	0.7907
Total change calculated from the trend (^{0}C /53 years)	1.737	0.650	1.487

***P <0.01 Student's t-test, N=53.

Total change is the difference between the trend line value of the first and last year.

b. Rainfall Changes

In total, 85.58% of the respondents observed changes in rainfall patterns over the past 20 years. The distribution of the farmers' perceptions regarding changes in rainfall patterns revealed that 74.61% perceived an increase in rainfall and 37% perceived a decrease in rainfall. In the Maritime region, 94% of farmers perceived decrease in rainfall, while in the

Plateaux region it is 62% and 63% in the Savannah region. Despite higher perception of the farmers interviewed on changes in rainfall patterns, 6.58% of the farmers interviewed did not see any change in rainfall patterns (Figure 4.5).

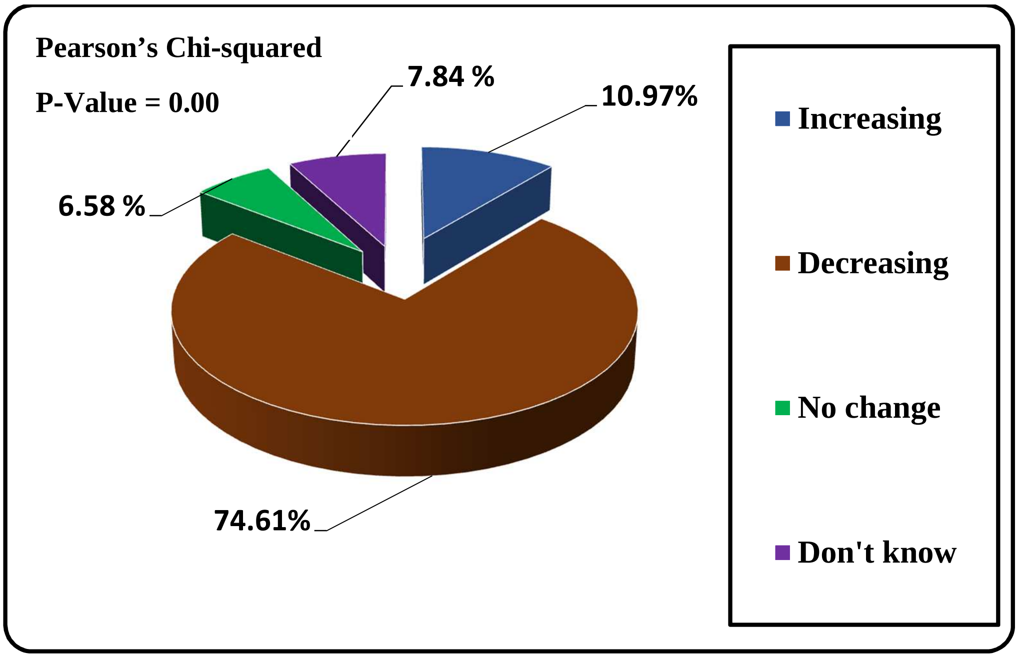

Figure 4.3. Farmers' perceptions of changes in rainfall

The recorded data on rainfall from 1961 to 2013 showed a slight decreasing trends for Maritime and Plateaux regions while for savannah region, the trend is slightly increasing. In addition, all these trends are not statistically significant. The correlation between rainfall and time is also insignificant. Indeed, there is a large variability in the amount of precipitation from year to year. The same pattern is observed in each district (Table 4.6). Therefore, farmers' perceptions of a reduction in rainfall over the past 20 years is explained by the fact that, as Maddison (2006) noticed, some farmers place more weight on recent information than is efficient.

Table 4.6. Analysis of the rainfall data from 1961 to 2013

Yearly Total Rainfall	Maritime Region	Plateaux Region	Savannah Region
Mean (mm)	942.7	1514.2	1054.4
Standard deviation (mm)	193.06	263.86	120.99
Minimum rainfall (mm)	557.1	982.6	808.6
Maximum rainfall (mm)	1528.2	2150.7	1323.4
Trend (mm/year)	-1.142	-2.625	0.181
Correlation	-0.0913	-0.1537	0.0231
Total change calculated from the trend (mm /53 years)	-59.38	-136.52	9.42
Total change calculated from the trend (%)	-6.11	-8.63	0.89

Total change is the difference between the trend line value of the first and last year

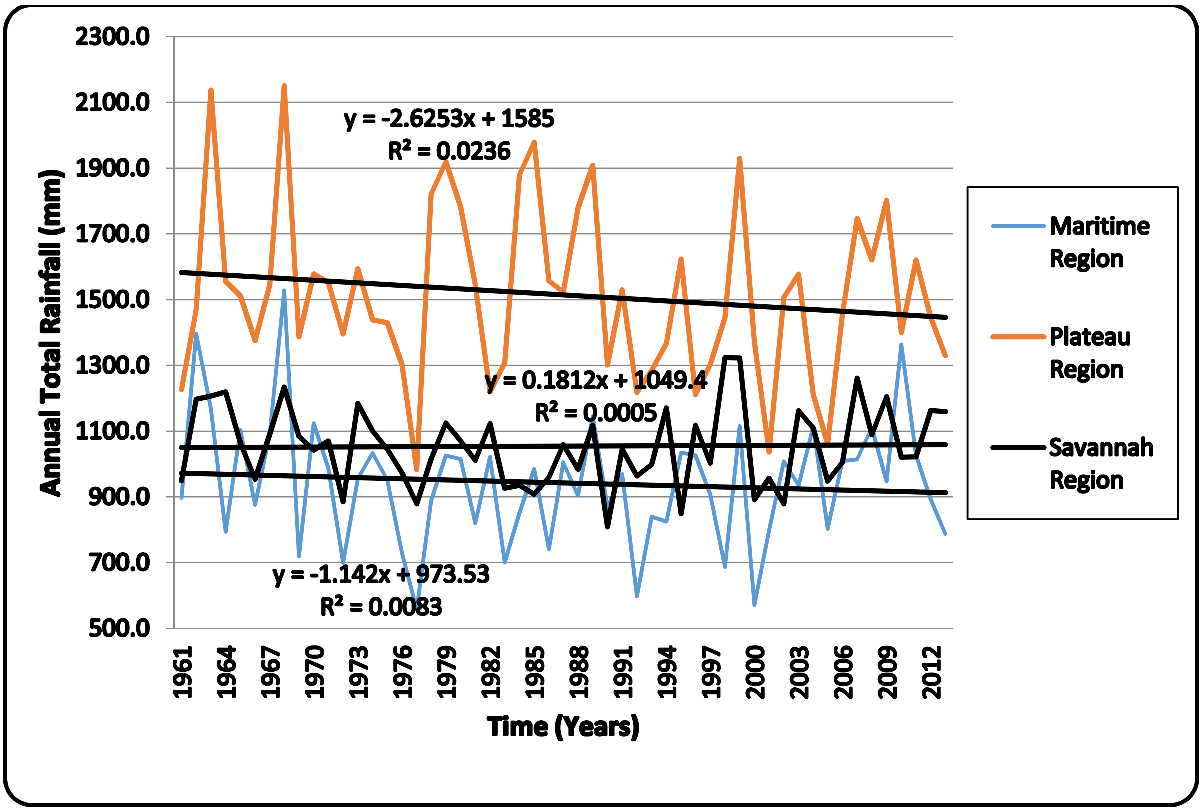

Figure 4.4. Rainfall linear trend 1961–2013

4.2.2 Logistic Regression of Determinants of Perception of Changes in the Climate

Table 4.7 presents the correlations between all the variables hypothesized to influence farmers' perception of changes in the climate: age, gender, education, farming experience, farm size, land tenure, soil fertility, access to extension services, access to credit, access to climate information and farmers' group membership. Among the variables, the age of the farmer was found to be correlated inversely with education ($\rho= -0.035$) and highly positive and significant at $p<0.01$ level of significance with farming experience ($\rho=0.825$). By the same token, there has been a strong positive association between gender and land tenure $p<0.01$. Most importantly, the analysis showed that the correlation between age and farming experience is higher than 0.80, which is a strong indication of multi-collinearity between the two variables. Thus, the variable age was dropped from the model. In addition, table A.2 (Appendix I) provides the summary statistics of the independent variables included in the analysis.

The independent variables are gender, education, farming experience, farm size, land tenure, soil fertility, access to extension services, access to climate information, access to credit, farmers' group membership, and region dummy for Plateaux and Savannah with Maritime being the reference region for comparison.

The results displayed in table 4.8 below showed the following:

- Farming experience seems to decrease the probability that the farmer will perceive long-term changes in rainfall and temperature. Thus, educated farmers are more likely to see that rainfall does not have a significant trend and less likely to perceive that temperature does not have a significant trend over the long run.

- Male farmers are more likely to perceive change in temperature than female farmers;

- Owning a farm land, on the other hand, increases the probability of perceiving change in temperature;

- The results also confirm that being in the Plateaux Region or the Savannah Region decreases the probability of perceiving climate change (in temperature and rainfall) than being in the Maritime region;

- Also, farm size, access to credit, access to extension services, being member of farmers' association, and soil fertility influence positively farmers' perception of changes in the climate of the study area.

Table 4.7. Correlation matrix of the independent variables

	Gender	Age	Education	Farming experience	Farm size	Land tenure	Soil fertility	Extension	Credit	Farmers' group	Climate information
Gender	1.0000										
Age	-0.0959	1.0000									
Education	0.1767*	-0.0351	1.0000								
Farming experience	-0.1311*	0.8253*	-0.0466	1.0000							
Farm size	-0.0186	0.1274*	0.0912	0.1372*	1.0000						
Land tenure	0.3535*	0.0445	-0.0639	-0.0420	-0.1305*	1.0000					
Soil fertility	0.1150*	0.0485	-0.0470	0.0343	-0.0210	0.2594*	1.0000				
Extension	-0.0292	0.1840*	0.0252	0.2648*	0.2433*	-0.0798	-0.0515	1.0000			
Credit	-0.0348	0.1524*	0.1183*	0.1294*	0.1294*	-0.0003	-0.0342	0.3576*	1.0000		
Farmers' Group	0.2197*	-0.0046	0.0047	-0.0957	-0.1052	0.2409*	0.1068	0.0496	0.1057	1.0000	
Climate information	0.0839	0.0860	0.0734	0.1098	0.2011*	0.0008	0.0763	0.3085*	0.1534*	-0.0202	1.0000

*p<.01. All correlations are Pearson's r.

Table 4.8. Logistic regression of farmers' perception of changes in the climate in the study area

VARIABLES	COEFFICIENTS(in log-odds unit)	
	Perceive change in temperature	Perceive change in rainfall
Gender	0.80* (1.73)	0.41 (0.95)
Education level	-0.06 (-1.04)	-0.02 (-0.40)
Farming experience	-0.13** (-2.29)	-0.19*** (-3.41)
Farm size	0.32 (0.91)	0.17 (0.59)
Land tenure	1.22*** (3.00)	0.17 (0.45)
Soil fertility	0.47 (0.75)	0.82 (1.52)
Access to extension	0.60 (1.19)	0.33 (0.74)
Access to credit	0.07 (0.11)	-0.45 (-0.79)
Farmers' group membership	0.33 (0.76)	0.50 (1.15)
Access to climate information	-0.58 (-1.44)	-0.54 (-1.35)
Plateaux region	-2.52** (-2.54)	-3.14*** (-3.48)
Savannah region	-3.04*** (-3.30)	-3.40*** (-3.89)
Constant	0.12 (0.09)	1.22 (0.83)
Observations	316	316

*** p<0.01, ** p<0.05, * p<0.1
Robust z-statistics in parentheses

Considering the results of farmers' perception of changes in temperature and rainfall discussed above, the part of the fifth specific objective on perception is achieved.

4.3 Farmers' Adaptation Analysis

4.3.1 Adaptation Strategies by Farmers in the Face of Increased Temperature, Reduced Rainfall and Disrupted Rainfall Patterns

The adaptation methods employed by farmers in the study area are indicated in table 4.9. Even though a large number of farmers interviewed noticed changes in climate, almost 42% did not undertake any remedial actions. Indeed, seven adaptation measures could be identified in the study area as farmers' responses to increased temperature, reduced rainfall and disrupted rainfall patterns. Planting short season variety (20.38%) and changing crop planting dates (17.87%) were identified as the major adaptation strategies to climate change in the study area, while only a few (9.72%) opted for crop diversification. As indicated, planting short season variety is most commonly used method, whereas changing type of crops is the least practised among the major adaptation methods identified in the study area. Greater use of planting short varieties as an adaptation method could be associated with the access to extension services (ICAT and NGOs) and the ongoing PNIASA project in agriculture sector in Togo that provided farmers with improved seeds.

Table 4.9. Adaptations strategies in response to change in temperature and precipitation (%)

Adaptation strategies	Increase in temperature and Decrease in rainfall (%)
Crop diversification	9.72
Change in crops	0.94
Find off-farm jobs	3.76
Change the amount of land	1.88
Change planting dates	17.87
Plant short season variety	20.38
Other	3.76
No adaptation	41.69
Total	100

4.3.2 Determinants of Farmers' Adaptation Choices

In this section, the MNL model for adaptation choices to climate change in the study area was estimated by using the statistical software Stata version 11.2. The MNL adaptation model was run and tested for the IIA assumption, using the Hausman specification test. As a result, the test failed to reject the null hypothesis of independence of odds of other alternative (Appendix II), suggesting there is no evidence against the correct specification for the adaptation model. Therefore, the application of the MNL specification to the data set for modelling climate change adaptation behaviour of farmers is justified. The estimation of the multinomial logit model for this study was undertaken by normalizing one category, which is normally referred to as the ''reference state,'' or the ''base category.'' In this analysis, the first category (no adaptation) is the reference state. Thus, Table 4.10 displays the estimated coefficients which should be compared with the base category that is "no adaptation". The likelihood ratio statistics as indicated by $\chi^2 = 301.39$ are highly significant at 1%, suggesting strong explanatory power of the model.

The following summarizes results from the MNL analysis:

Education level of the farmers increases the probability of uptake of adaption options climate change. As can be observed in Table 4.10, education level significantly increases planting short season variety as an adaptation method in the study area. Moreover, the coefficient of change in crops is positive indicating a positive relationship between education and change in crops as adaptation method to climate change. These results are consistent with findings by Deressa et al. (2009) and Ajao and Ogunniyi (2011).

Farmer experience increases the probability of uptake of crop diversification, changing planting dates and planting short season variety as adaptation measures. Experienced farmers are more likely to adopt changing planting dates and planting short season variety and less likely to diversify crops in the study area. These results confirm the findings of Nhemachena and Hassan (2007), Gbetibouo (2009) and Ajao and Ogunniyi (2011). The import is that highly experienced farmers are likely to have more information and knowledge on changes in climatic conditions. Experienced farmers are usually leaders and progressive farmers in rural communities and these can be targeted in promoting adaptation management to other farmers who do not have such experience and are not yet adapting to changing climatic conditions.

Access to extension services significantly increases the probability of taking up adaptation options in the study area. Indeed, farmers who have access to extension services are more likely to adopt planting short season variety and less likely to diversify crops and to change planting dates as adaptation options. Extension services provide an important source of information on climate change as well as agricultural production and management practices. Farmers who have significant extension contacts have better chances to be aware of changing climatic conditions and also of the various management practices that they can use to adapt to changes in climatic conditions.

Access to credit: As expected, the results show that having access to credit increases the propensity of farmers to adapt to climate change. Farmers who have access to credit are more likely to adopt planting short season variety and less likely to find off-farm jobs in the study area.

Table 4.10. Multinomial logit (MNL) adaptation model

VARIABLES	COEFFICIENTS (in log-odds unit)						
	Crop diversification	Change in crops	Find off-farm jobs	Changed the amount of land	Changed planting date	Plant short season variety	Others
Gender	0.12	0.21	0.37	-0.97	-0.54	-0.72	0.05
	(0.21)	(0.14)	(0.50)	(-0.93)	(-1.09)	(-1.51)	(0.06)
Education level	-0.04	0.00	-0.11	-0.18	-0.03	0.13**	-0.17
	(-0.51)	(0.02)	(-0.85)	(-0.75)	(-0.45)	(2.02)	(-1.07)
Farming experience	0.09*	0.13	0.03	-0.11	0.11***	0.09**	0.03
	(1.94)	(0.78)	(0.54)	(-0.62)	(2.69)	(2.20)	(0.42)
Farm size	0.32	-0.68	-0.63	0.41	0.37	0.37	-0.50
	(1.26)	(-0.39)	(-0.85)	(0.86)	(1.53)	(1.57)	(-0.59)
Land tenure	-1.14**	-1.45	-2.17**	0.99	-1.31***	-0.45	-0.79
	(-2.07)	(-0.77)	(-2.55)	(0.95)	(-2.70)	(-0.97)	(-0.97)
Soil fertility	-2.47**	-15.04	0.79	-16.98	-1.54**	-0.76	0.77
	(-2.22)	(-0.01)	(1.07)	(-0.00)	(-2.36)	(-1.38)	(1.13)
Access to extension	1.00*	1.84	-0.40	0.81	0.82*	1.94***	-0.25
	(1.82)	(0.88)	(-0.45)	(0.79)	(1.69)	(4.14)	(-0.30)
Access to credit	0.43	2.80	2.41**	-16.02	0.95	1.63***	1.68*
	(0.50)	(1.17)	(2.48)	(-0.00)	(1.32)	(2.61)	(1.66)
Farmers' group membership	-2.32***	-18.36	-0.52	-0.22	-2.23***	-1.01*	16.22
	(-4.09)	(-0.01)	(-0.56)	(-0.19)	(-4.27)	(-1.85)	(0.01)
Access to climate information	0.84	1.76	0.43	0.55	2.65***	1.93***	0.15
	(1.51)	(0.82)	(0.55)	(0.54)	(5.44)	(4.34)	(0.20)
Constant	-2.40**	-0.16	-3.82**	0.08	-1.59*	-2.43**	-18.29
	(-2.29)	(-0.05)	(-2.35)	(0.03)	(-1.65)	(-2.53)	(-0.01)
Observations	316	316	316	316	316	316	316

*** p<0.01, ** p<0.05, * p<0.1
Z-statistics in parentheses

The import is that poverty or lack of financial resources is one of the main constraints to adjustment to climate change and thus having access to credit counteracts these constraints. Also, with more financial and other resources at their disposal, farmers are able to change their management practices in response to changing climatic conditions.

Access to climate information: As expected, access to information on climate change (temperature and rainfall) has a significant and positive impact on farmers' adopting changing planting dates and planting short season varieties. These results are in line with findings by Ajao and Ogunniyi (2011) and Deressa et al. (2009). Moreover, almost all of the coefficients of access to climate information are positive across all the manifold adaptation options in the study area indicating a positive relationship between climate information and adaptation to climate change.

Surprisingly, land tenure, soil fertility and membership in farmers' group have decreased the farmers' propensity to adopt crop diversification, off-farm jobs, planting short season variety and changing planting dates as adaptation measures to climate change in the study area. So, the above discussion on farmers' adaptation to changes in temperature and rainfall constitutes the achievement of the part of the fifth specific objective of our study on adaptation.

CHAPTER 5: CONCLUSIONS AND POLICY RECOMMENDATIONS

As mentioned earlier, this study is an attempt to assess the economic impact of climate change on crop production in Togo using the Ricardian model. It tested two models: model without adaptation and model with adaptation. Annual net revenue and gross revenue per hectare were regressed on climate, socioeconomic and soil variables. The regression results were then applied to possible future Representative Concentration Pathways (RCP8.5) scenarios for Togo on temperature and rainfall.

The primary data were obtained from a survey conducted in the 35 districts of Togo in the framework of the national agricultural census (RNA) 2012/2013 by the National Agricultural Statistics Service (DSID). The climatic data came from the National Meteorological Service of Togo (DNM) and covered the period from 1961 to 2012, while soil data were obtained from Harmonized World Soil Database (HWSD), version 1.2 (2012).

The empirical results from this study provide certain evidence that climate affects crop net revenue in Togo. Results also suggest that climate has a nonlinear effect on net revenue from crop production. In rainy season, the marginal impact of temperature on revenue shows that if the temperature increases by 1°C, the net crop revenue falls by US$340.33/ha, while, on the other hand, if the rainfall increases by 1 mm, the net revenue increases by US$3.55/ha. Furthermore, the results showed that marginally increasing rainfall during the dry season reduces the net revenue by US$7.08/ha, whereas in dry season, marginally increasing temperature would lead to an increase in the net revenue.

The results of Representative Concentration Pathways (RCP8.5) scenarios indicate that increasing temperature, as well as the simultaneous effects of a reducing rainfall and an increasing temperature, reduces crop revenue very substantially in magnitude. A warming of temperature by 2°C will lead to a decrease by 62.02% in the net revenue in 2050, whereas simultaneously an increase of 2°C in the temperature and a decrease of 10% in the rainfall will lead to 80.75% fall in the net revenue in 2050 in Togo.

The study reveals that some variables used in the regression are significant and have a positive effect on net revenue. For instance, livestock ownership is significant and has a positive effect, while education level, access to extension services and farm size have a positive effect but are not significant on the net revenue. The above-mentioned variables can be applied as adaptation options.

In this study, we also analysed the factors affecting the farmers' perceptions and choice of adaptation methods to climate change based on a cross-sectional survey data collected during the 2013/2014 agricultural production year in the Maritime, Plateau and Savannah regions of Togo. The surveyed farmers were asked if they have observed any change in the temperature and rainfall over the past 20 years. As a result, about 72% of the farmers perceived increases in temperature while in total, 85.58% of the respondents observed changes in rainfall patterns over the past 20 years. These results are in line with the climatic data records in the study area because the statistical analysis of temperature data from 1961 to 2013 showed an increasing trend in the three regions and rainfall data showed decreasing trends for the Maritime and Plateaux regions while for Savannah region, the trend is slightly increasing.

Regarding the determinants of farmers' perceptions of climate change, male farmers are more likely to perceive change in temperature than females; owning a farm land, on the other hand, increases the probability of perceiving change in temperature; and being in the Plateaux region or Savannah region decreases the probability of perceiving climate change (in temperature and rainfall) than being in the Maritime region.

Although farmers appear to be well aware of climate change, few seem to actively undertake adaptation measures to counteract climate change. Indeed, almost 42% did not undertake any remedial actions. The adaptation options observed in the study area are manifold but the main adaptation strategies of farmers identified include planting short season variety and changing crop planting dates.

The study uses the multinomial logit (MNL) model to assess the factors influencing farmers' choices of climate change and variability adaptation methods. In the model, the dependent variables include different adaptation methods and the explanatory variables include household, farm and institutional characteristics and other factors. The results highlighted that education level, farming experience, access to extension services, access to credit and access to climate information are the factors that enhance farmers' adaptive capacity to climate change and variability.

This study demonstrates the importance of government policies and strategic investment plans that support improved access to climate forecasting and dissemination, ensure that farmers have access to affordable credit schemes to increase their ability and flexibility to adopt adaptation measures in response to the forecasted climate conditions.

Moreover, given that extension services are inadequate in the study area, improving the knowledge and skills of extension service personnel and making the extension services more accessible to farmers appear to be some of the key elements of a fruitful adaptation program. It is also important to enhance Research and Development and introduce new crops/varieties that will give farmers a hand in adapting to harsh climatic conditions. Finally, investment in education systems and creation of off-farm job opportunities in the rural areas can be underlined as a policy option regarding reduction of the adverse impacts of climate change in the study area.

There are a number of caveats that readers should keep in mind when interpreting the results of this study. First, the cross sectional analysis is vulnerable to omitted variables; second, the analysis did not consider carbon fertilization which is predicted to increase future crop productivity; third, the analysis did not include changes in prices; and fourth, the analysis did not take into account future technological changes. Then, the study considered technology to be a constant and in predicting impacts of climate change did not take into account farmers' ongoing adaptations. The study looked at crops overall and did not examine the impact crop by crop. Future studies should take an interest in the mono crop model. This would permit researchers to target those crops most important for the country, for example maize and sorghum that are staple food in Togo.

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APPENDICES

APPENDIX I: Summary Statistics

Table A.1. Summary statistics of variables used in the Ricardian model

Variables	N	Mean	Std. Dev.	Min	Max
Crop Net revenues(US$)	1337	511.152	781.49	-568.54	4097.01
Crop Gross Revenues(US$)	1337	766.34	873.67	17.37	9379.08
Rainy season precipitation(mm)	1337	152.00	25.97	111.82	205.30
Rainy season precipitation squared(mm)	1337	23777.95	7961.97	12503.49	42147.57
Dry season precipitation(mm)	1337	49.39	25.74	13.42	105.75
Dry season precipitation squared(mm)	1337	3101.33	2867.74	180.01	11183.66
Rainy season temperature(^oC)	1337	26.63	0.62	23.98	27.71
Rainy season temperature squared(^oC)	1337	709.65	32.41	575.10	768.07
Dry season temperature(^oC)	1337	27.43	0.95	24.45	29.48
Dry season temperature squared(^oC)	1337	753.22	51.79	597.99	869.09
Nitisols(0/1)	1337	0.37	0.48	0	1
Lixisols(0/1)	1337	0.51	0.50	0	1
Leptosols(0/1)	1337	0.04	0.19	0	1
Vertisols(0/1)	1337	0.04	0.21	0	1
Plinthosols(0/1)	1337	0.03	0.17	0	1
Sex of household head(0/1)	1337	0.80	0.40	0	1
Age of household head(Years)	1337	46.65	14.78	15	99
Marital status of household head(0/1)	1337	0.96	0.19	0	1
Size of household	1337	5.18	3.42	1	15
Education level of household head	1337	1.52	1.39	0	6
Livestock ownership(0/1)	1337	0.73	0.44	0	1
Access to extension services(0/1)	1337	0.21	0.41	0	1
Population density	1337	124.30	91.40	28.13	376.69
Population density squared	1337	23796.42	34533.42	791.22	141896.50
Crop land area (ha)	1337	0.50	1.19	0.01	4.58

Table A.2. Summary statistics of the variables in the logistic regression

Variables	Observations	Mean	Standard deviation	Minimum	Maximum
Age	319	38.71	11.65	17	85
Education level	319	2.16	3.15	0	14
Farming experience	317	16.18	10.05	1	60
Farm size	319	.77	.98	.06	8
	Choices	**Frequency**	**Percent**	**cumulative**	
Gender	0	109	34.17	34.17	
	1	210	65.83	100	
Land tenure	0	153	47.96	47.96	
	1	166	52.04	100	
Soil fertility	0	258	80.88	80.88	
	1	61	19.12	100	
Access to extension	0	182	57.05	57.05	
	1	137	42.95	100	
Access to credit	0	269	84.33	84.33	
	1	50	15.67	100	
Farmers' group membership	0	78	24.53	24.53	
	1	240	75.47	100	
Access to climate information	0	189	59.43	59.43	
	1	129	40.57	100	
Maritime region	0	201	63.01	63.01	
	1	118	36.99	100	
Plateau region	0	218	68.34	68.34	
	1	101	31.66	100	
Savannah region	0	219	68.65	68.65	
	1	100	31.35	100	

APPENDIX II: Hausman Tests of IIA Assumption (MNL Model)

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**** Hausman tests of IIA assumption (N=316)

 Ho: Odds(Outcome-J vs Outcome-K) are independent of other alternatives.
```

Omitted	chi2	df	P>chi2	evidence
crdv	0.000	4	1.000	for Ho
cinc	0.000	2	1.000	for Ho
offj	0.000	4	1.000	for Ho
caml	0.000	2	1.000	for Ho
chpd	0.000	4	1.000	for Ho
psht	0.000	4	1.000	for Ho
oth	0.000	4	1.000	for Ho
noad	0.000	4	1.000	for Ho

APPENDIX III: RCP8.5 scenarios on rainfall: horizon 2025 and 2050

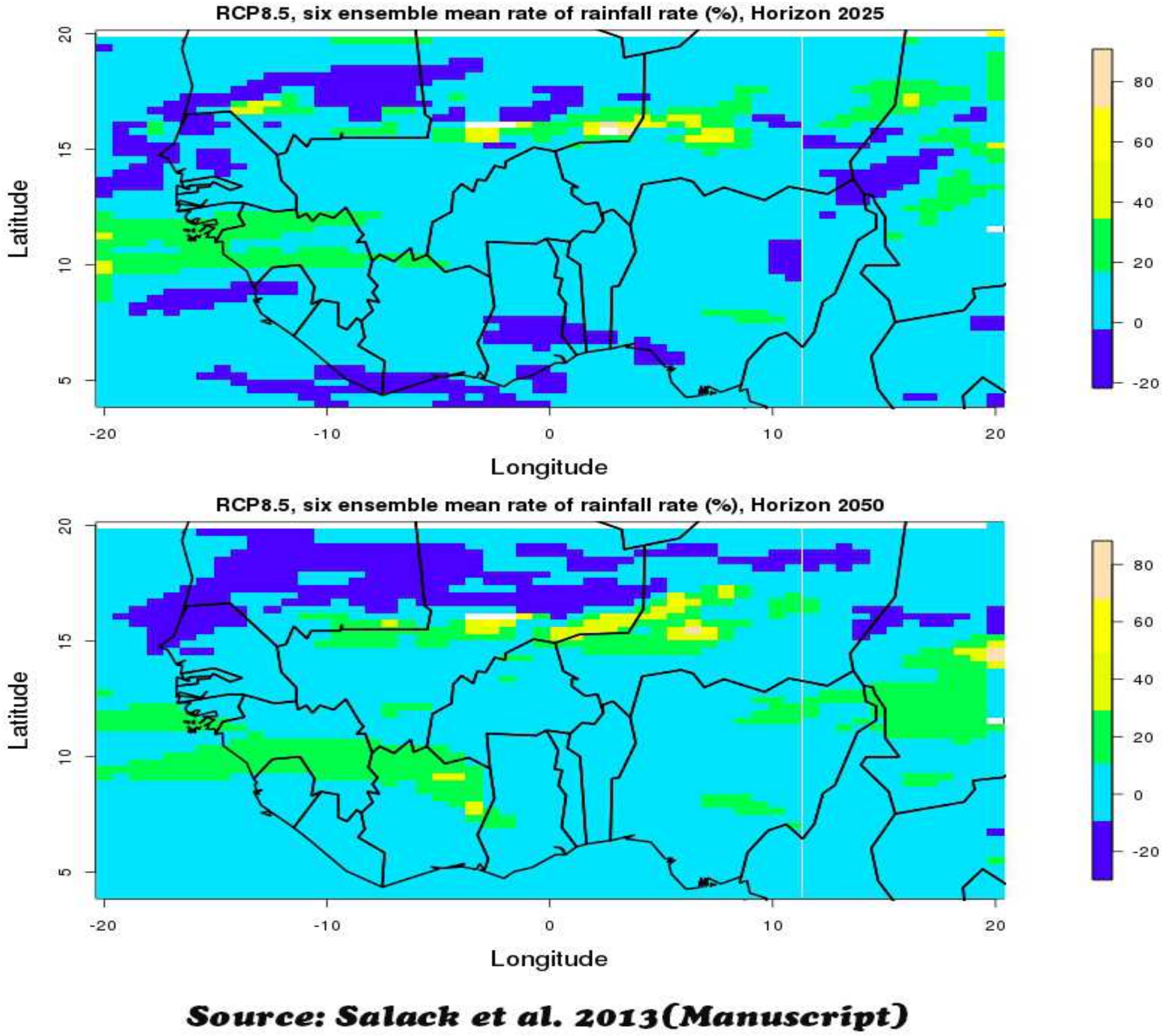

Figure A.1. RCP8.5 scenarios on rainfall: horizon 2025 and 2050

APPENDIX IV: RCP8.5 scenarios on temperature: horizon 2025 and 2050

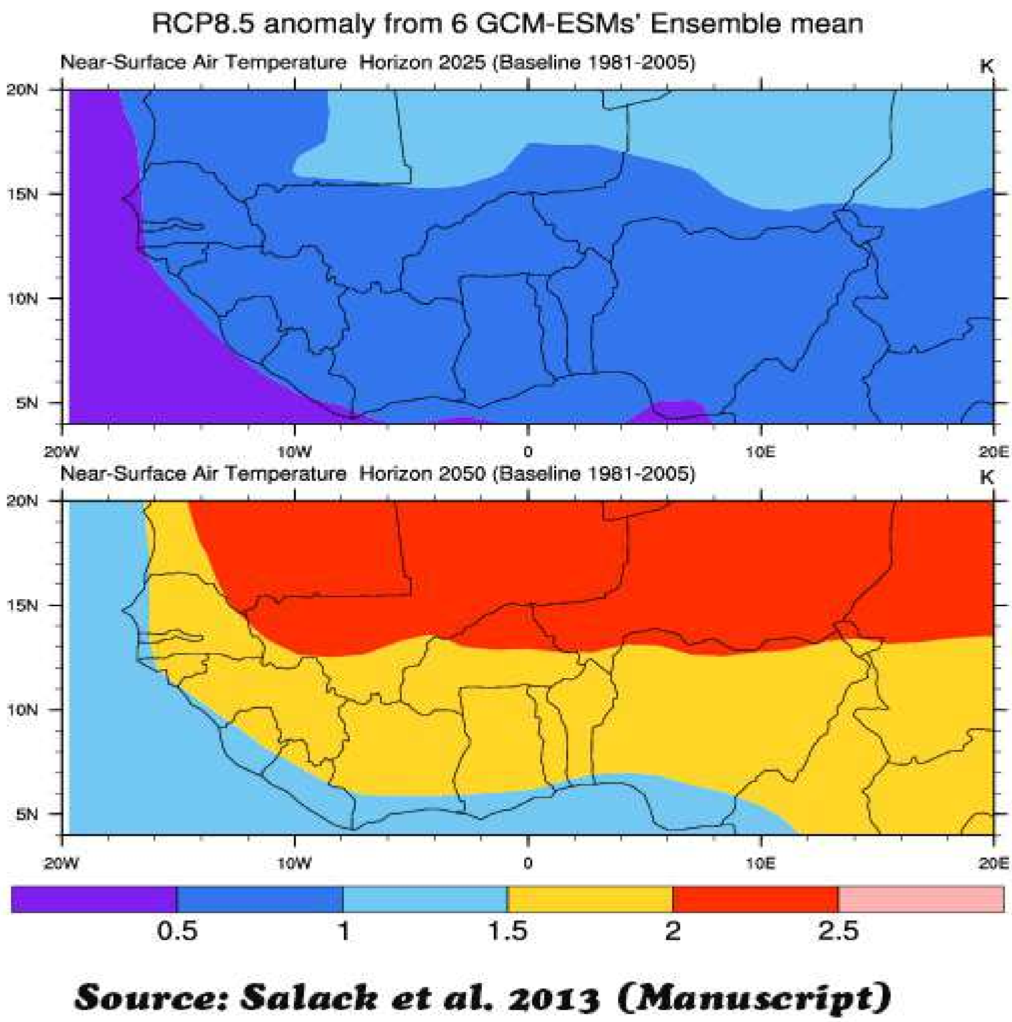

Figure A.2. RCP8.5 scenarios on temperature: horizon 2025 and 2050

APPENDIX V: Interpolation of the rainfall

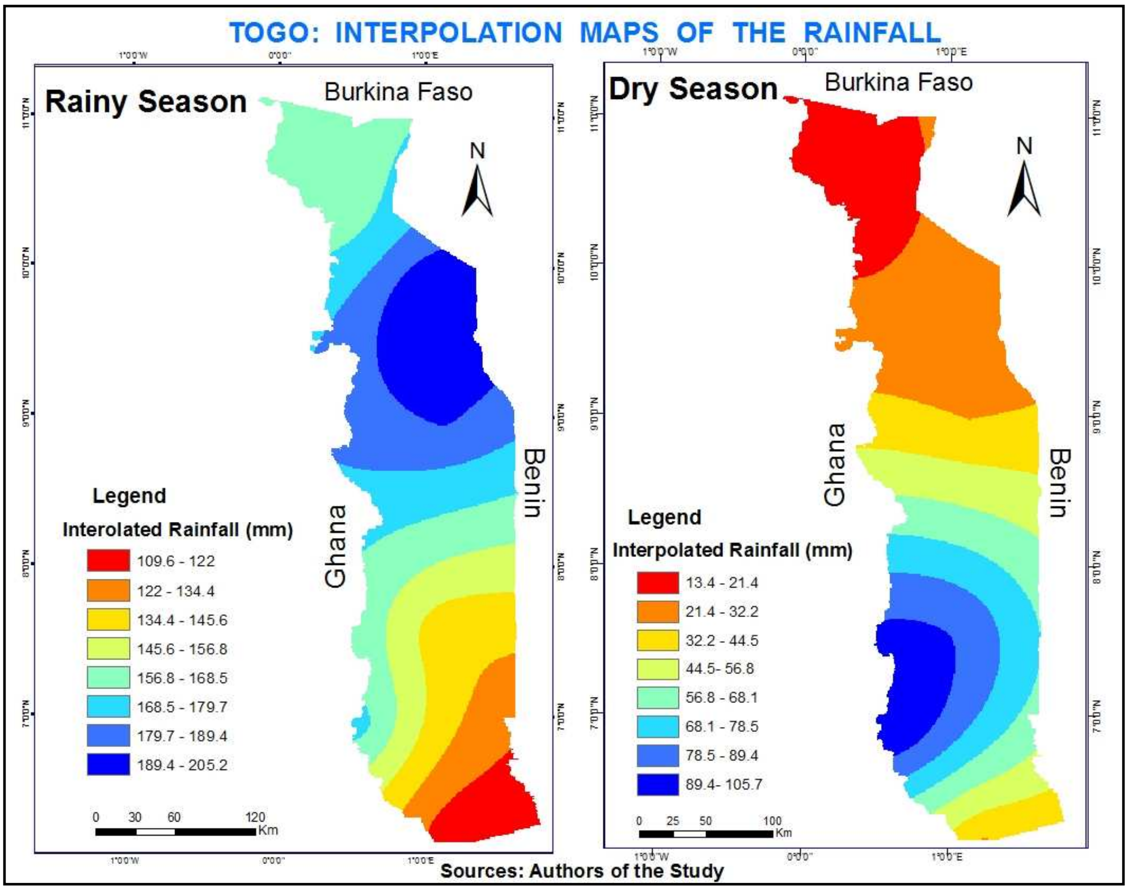

Figure A.3. Interpolation of the rainfall

APPENDIX VI: Interpolation of the temperature

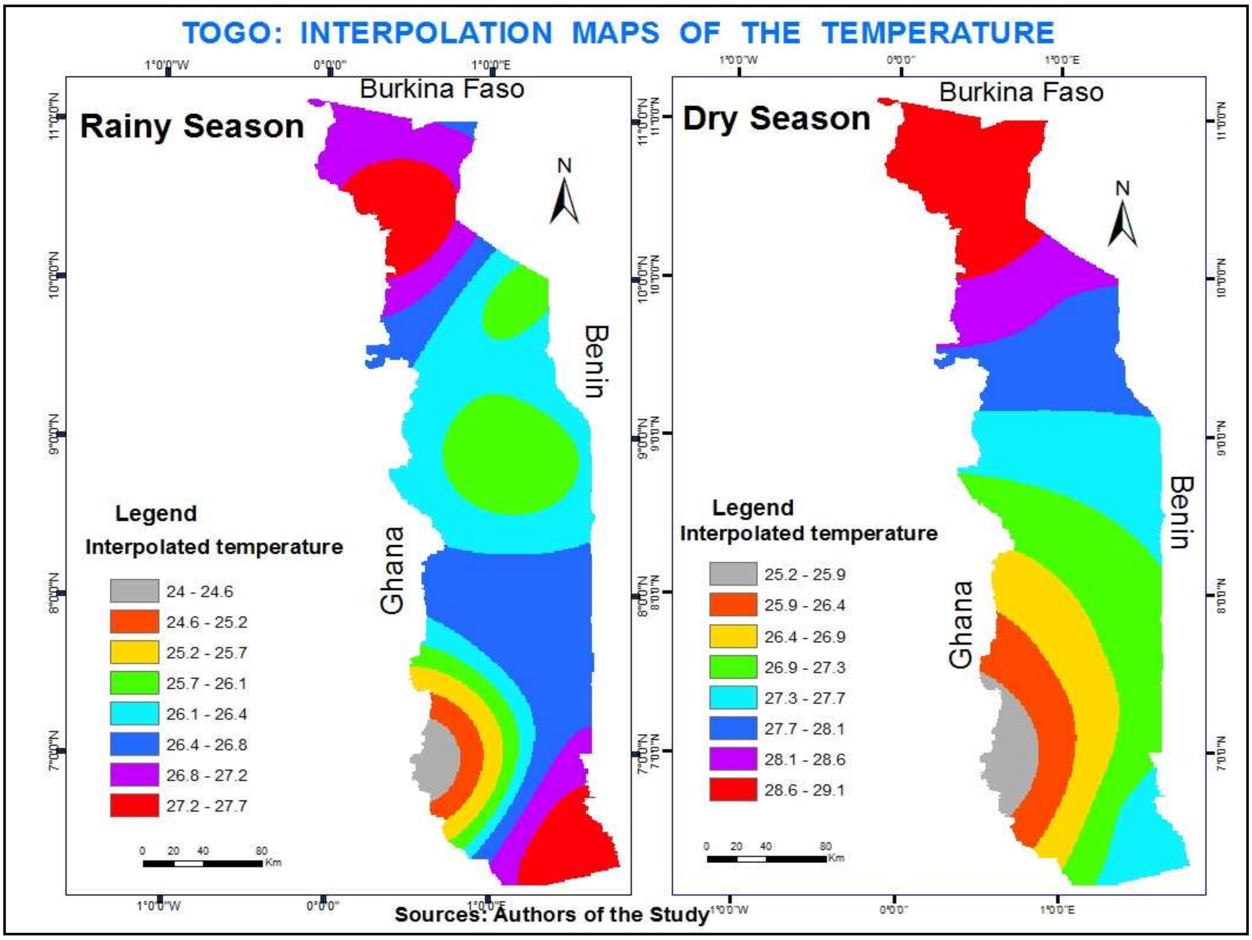

Figure A.4. Interpolation of the temperature

APPENDIX VII: Soil map of Togo

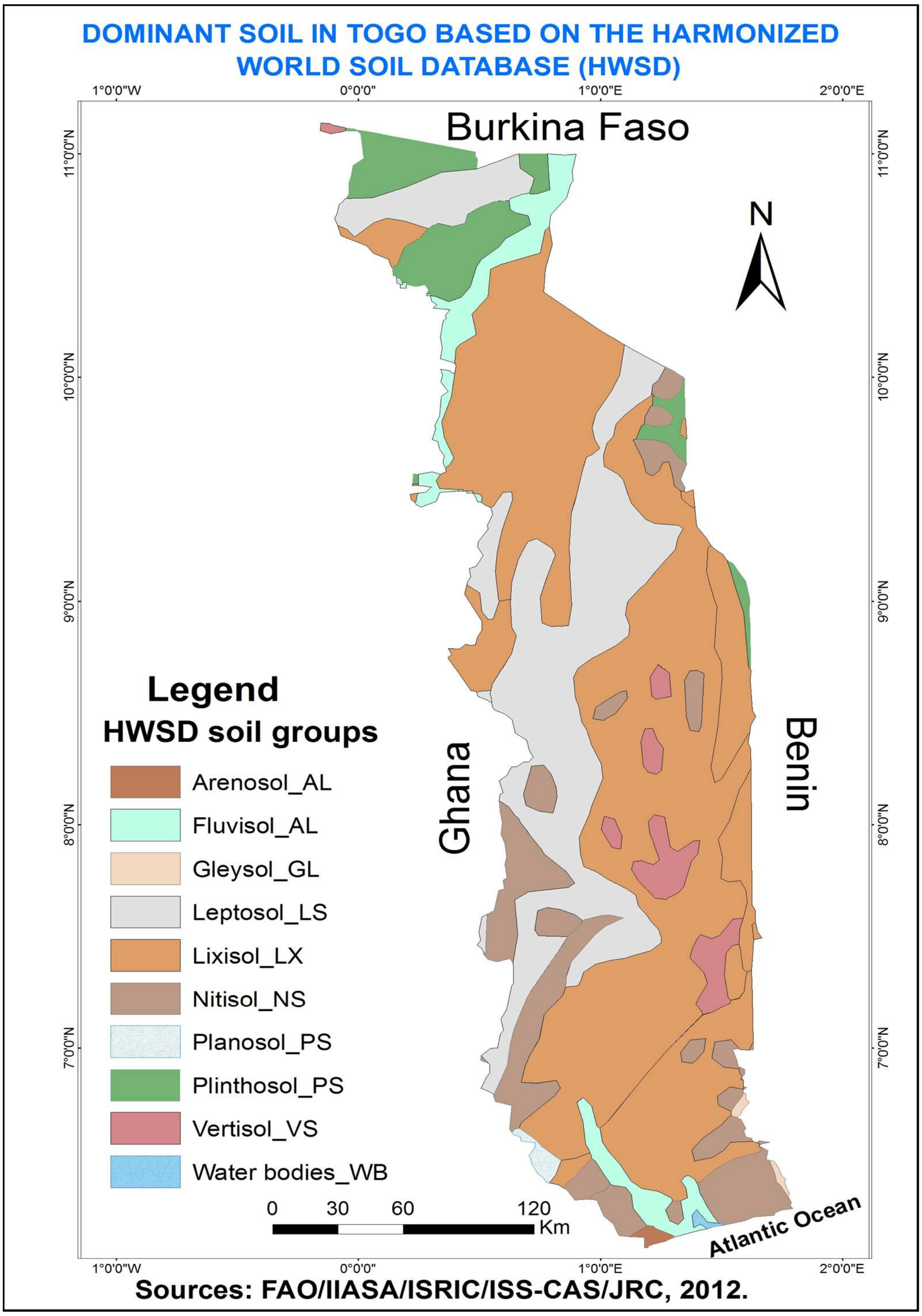

Figure A.5. Soil Map of Togo

APPENDIX VIII : Questionnaire

INDIVIDUAL QUESTIONNAIRE ON FARMERS' PERCEPTION AND ADAPTATION TO CC

MASTER OF SCIENCE IN CLIMATE CHANGE AND HUMAN SECURITY

THE IMPACT OF CLIMATE CHANGE ON CROP PRODUCTION IN TOGO

SECTION 1 : LOCALISATION

1.0.Day/Month/year of the interview :	___ ___ / ___ ___ / 2014
1.1. REGION : ____________________	1.4. VILLAGE /VILLE : ______________________
1.2. Prefecture ______________________	1.5 Number of the questionnaire !____! ____ !
1.3. District: _________________________	1.6 Respondent's name ______________________

SECTION 2 : SOCIO-DEMOGRAPHIC CHARACTERISTICS		
2.1	Gender	1. Male |___| 2. Female |___|
2.2	How old are you?	1. Teenager (13-19ans) |___| 2. Adolesents (20-39ans) |___| 3. Adults (40-60ans et plus) |___|
2.3	Education level of the respondent	1. None …..|___| 2. Teaching to read and write |___| 3. Primary school |___| 4. JSS (6è, 5è, 4è, 3è) |___| 5. JHS (2è, 1ère, Terminale) |___| 6. University |___|
2.4	Marital status	1. Single |___| 2. Married |___| 3. Widow/widower |___|
2.5	How many people are living with you and you actually take care of them	|___|___|

SECTION 3 : SOCIO-ECONOMIC CHARACTERISTICS				
3.1a	What is your main activity?	1. Agriculture |___| 2. livestock farming |___| 3. Fishing |___| 4. Forestry |___| 5.Aquaculture |___| 6. Bee farming |___| 7. Handicraft |___| 8. Other(To be mentioned) -- -------------------------------------	**3.1b** which other acivity do you exercise?	1. Agriculture |___| 2. Livestock farming |___| 3. Fishing |___| 4. Forestry |___| 5.Aquaculture |___| 6. Bee farming |___| 7. Handicraft |___| 8. Other (To be mentioned) -- --
3.2	How long have you been doing this activity?	|___|___|___|		
3.3	What is the size of your farm under exploitation (ha)?	|___|___|___|		
3.4	Are you the owner of your farm land?	1. Yes |___| 2. No |___|		
3.7	Amount of fertilizers used	1. Increase |___| 2. Decrease |___| 3. No change |___| 3- Don't know |___|		
SECTION 4 : INSTITUTIONAL CHARACTERISTICS				
4.1	Have you access to extension services?	1. Yes |___| 2. No |___|		
4.2	If yes how it is done?			
4.3	Which institutions are the providers of these services?	1. ICAT |___| 2. NGOs |___| 3. Other (To be mentioned) --		
4.4	Have you access to credit?	1. Yes |___| 2. No |___|		
4.5	If yes, under which form is this credit?			
4.6	Are you a member of farmers association?	1. Yes |___| 2. No |___|		

SECTION 5 : CLIMATE CHANGE PERCEPTION		
5.1	Change in the temperature during the past 20 years	1. Increase |___| 2. Decrease |___| 3. No change |___| 3- Don't know |___|
5.2	Change in the rainfall pattern during the past 20 years	1. Increase |___| 2. Decrease |___| 3. No change |___| 3- Don't know |___|
5.3	Change in the growing season	1. Late rainy season onset |___| 2. Early rainy season cessation |___| 3. No change |___| 4. Don't know |___|
5.4	Which strategy do you use to adapt to these changes?	1-Crop diversification |___| 2. Change in crops |___| 3. Off-farm jobs |___| 4. Decrease of the size of farm under exploitation |___| 5. Increase of the size of farm under exploitation |___| 6. Change in planting date |___| 7. Planting of short season variety |___| 8. Other (To be mentioned) :-- 9. No adaptation |___|
5.5	What is your expectation of the government or other institutions in terms of support?	

NB: CC= Climate Change

VITA

Agossou Gadedjisso-Tossou received his engineering diploma in Agricultural Economics from the Université de Lomé (Togo) in 2009. Then, he worked with The Laboratory of Research on Poverty and Sustainable Food Security (LARPSAD) at Université de Lomé as research assistant from 2009 to 2011. He entered the master research programme on Natural Resource and Environment Management at the Department of Economics and Rural Sociology of School of Agriculture (ESA) at Université de Lomé in February 2011. He did his English proficiency at the University of Cape Coast in 2012 and at the American Embassy English Language Center (ELC) in Togo in 2013 where he took a paper-based TOEFL. He received his Master of Science degree in Climate Change and Human Security from the West African Science Service Center on Climate Change and Human Security (WASCAL), Université de Lomé (Togo) in November 2014. His research interests include agricultural economics, climate change impacts, vulnerability analysis, sustainable development and econometrics.

His email address is gadedjissotossou@gmail.com