ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF ECONOMICS

CLIMATE CHANGE AND CROP AGRICULTURE IN NILE BASIN OF ETHIOPIA: MEASURING IMPACTS AND ADAPTATION OPTIONS

BY

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ECONOMICS UNDER NATURAL RESOURCE AND ENVIRONMENTAL ECONOMICS STREAM

MAY, 2009

ADDIS ABABA

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

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Acknowledgments

This study would never be completed without the contribution of many people to whom I would like to express my thanks. My special gratitude goes to my advisor, Dr.Wassie Berhanu for his encouragement and guidance. I am also grateful to African Economic Research Consortium (AERC) for their financial support.

I would like to thank the following people for their contribution in providing relevant papers, data and their invaluable advice in improving my work with respect to their discipline: Dr. Tekie Alemu of Addis Ababa University, head of department of economics; Dr. Gezahegne Ayele and Dr. Taddesse Kumma of EDRI; Temesgen Tadesse of IFPRI, Senior Research Fellow, USA; Claudia Ringer of IFPRI, Senior Research Fellow, USA and Elizabeth Bryan of IFPRI, Senior Research Assistant, USA.

I am indebted to Tewodros Tebekew, Ayanaw Amogne of EDRI and Yabebal Ayalew of Addis Ababa University. Despite their busy schedule, they were always willing to discuss about my work. The comments that they gave are highly acknowledge. I wish to thank my best friend Daniel Mahetote and staffs of the Department of Data Systems and Economy Wide Modeling to Support Policy Analysis in Ethiopia, EDRI.

Last but not the least my appreciation goes to my fiancée, brother, father, mother and Yeshitila Ayaleneh to their endless support.

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Abbreviations and acronyms

AEZ	Agro-ecological Zoning
CCC	Canadian Climate Change
CGM2	Canadian Global Climate Model 2
EDRI	Ethiopian Development Research Institute
EEPFE	Environmental Economics Policy Forum for Ethiopia
FAO	Food and Agriculture Organization
GCM	General Circulation Models
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GFDL	Geophysical Fluid Dynamics Laboratory
HadCM3	Hadley Centre Climate Model 3
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
MoFED	Ministry of Finance and Economic Development
MoWR	Ministry of Water Resources
PCM	Parallel Climate Model
SNNP	Southern Nation Nationalities and People
SRES	Special Report on Emissions Scenarios
VIF	Variance Inflation Factor

Abstract

This study assesses the economic impact of climate change on crop farming activities in Nile basin of Ethiopia. It uses the Ricardian model. It is based on farm data generated from 20 districts over 975 farmers. Annual crop net revenue is regressed on climate and other variables. The regression results are then applied to possible future climates. Estimated marginal impacts of the climate variables on crop net revenues indicate different results for temperature and precipitation and also for irrigated and dry land farms. The results from this analysis indicate that an annual increase of 1°C in temperature will have a positive impact on annual crop net revenues for irrigated farms, but a negative impact for dry land farms and farms that represent Nile basin of Ethiopia. However, marginal impact of increasing precipitation will increase crop net revenue for both irrigated and dry land farms. In addition, the study examines the impact of uniform climate scenarios on the crop net revenue per hectare of farmers. These are increasing temperature by $2.5^0 C$ *and* $5^0 C$ *; and decreasing precipitation by 7% and 14%. Based on the results of these simulations, the study predicts that crop net revenues will fall for all farms under the four uniform climate scenarios except irrigated ones for a* $2.5^0 C$ *increase in temperature. The study provides farmers' perceptions of climate changes and their adaptations to these. It also gives constraints on adaptation mechanisms. The results suggest that farmers are aware of climate changes. Most of them have noticed an increase in temperature and a decrease in precipitation, and that some have taken adaptive measures. The above analyses more or less show the magnitude and direction of the economic impact of climate change on agriculture. The findings generally provide an idea about increasing temperature and decreasing precipitation that are detrimental to the agricultural productivity. Dry land farms are most likely affected by climate changes. Irrigated farms will benefit in relative terms. But adaptation is part of human nature, so these*

alarming forecasts will certainly be mitigated. These findings suggest that Ethiopia should begin to plan for climate contingencies. Actions that make agriculture sectors more immune to climate can be taken in advance. Developing new crops that are more suitable to hot and dry conditions will help farmers to adapt to climatic conditions. Encouraging profitable irrigated systems will reduce the climate vulnerability of the agricultural sector. Therefore, the above guiding principles will be a priority if certain climate outcomes come to pass to support sustainable development policy.

CHAPTER ONE

INTRODUCTION

1.1 General background

Ethiopia is one of the least developed countries in the world, with a gross domestic product (GDP) of slightly more than US$10 billion and a population of 73.9 million. The economy remains heavily dependent on agriculture, which has been practiced since 4000 B.C. According to the Ministry of Finance and Economic Development (MoFED), the agriculture sector employs more than 80 percent of the labor force and accounts for 45 percent of the GDP and 85 percent of the export revenue (MoFED, 2006).

Small-scale, mixed crops and livestock farming dominate the agriculture sector. About eight million households use a small-scale farming method, which accounts for 95% of the total area under crops and for more than 90% of the total agricultural output. The largest proportion of food crops (94%) and coffee (98%) are produced by small-scale farmers. Traditional farm technologies, use of ox-drawn wooden ploughs with steel pikes and other time-honored farm equipments, minimal application of fertilizers and pesticides due to high input prices in the presence of credit constraints and weak extension services, and low use of improved seeds are common (Deressa, 2006).

Subsistence crop production in Ethiopia is traditional and rainfed, with very limited areas of irrigation. Small-scale traditional irrigation has been practiced for decades in the highlands, where small streams are diverted seasonally for limited dry season cropping. Medium and large-scale schemes are of more recent origin.

Ethiopian agriculture is not highly productive in general. Its improvement is constrained mainly because of climatic factors and soil and land degradation. This is triggered and exacerbated by improper land use such as cultivation of steep slopes, over cultivation and overgrazing, and other socio-economic constraints such as inappropriate policies, subsistence farming and declining farm size mainly due to population growth. Additionally, tenure insecurity, weak agricultural research and extension services, lack of agricultural marketing, inadequate transport network and use of agricultural inputs such as low use of fertilizers, improved seeds and pesticides, poor nutrition of livestock, low level of veterinary care, and livestock diseases are other constraints (Deressa, 2006).

Apart from these constraints, the history of drought is as old as the country it self. Between 253 B.C. and first century A.D., drought occurred every seven years. From the first century A.D. up to 1500 A.D, there were 177 droughts (famines) which killed millions of people. Between 1500 A.D. and 1950, 69 drought events occurred. Ethiopia has also suffered from extremes of climate, manifested in the form of frequent drought (1965, 1974, 1983, 1984, 1987, 1990, 1991, 1999, 2000, and 2002) along with recent flooding of 1997 and 2006 (Yesuf et al., 2008). These are because of the country's prominent location in the Sahel Region, a region with erratic rainfall and unpredictable climate variability.

Ethiopia enjoys extremely varied climatic conditions with an extensive altitude range that is suitable for different agricultural production systems. Taking the two extreme altitudes, temperature range from the mean annual of 34.5^0C in the Danakil Depression, while minimum temperatures fall below zero, with a mean of less than 0^0C, in the upper reaches of Mount Ras Degen (4620m), where light snowfalls are recorded in most years. Between these extremes are vast areas of plateau and marginal slopes where mean annual temperatures are between 10^0C and 20^0C. Climatic elements are affected by altitude and geographical

location. The rainfall is correlated with altitude. The middle and higher altitudes (above 1500m) receive considerably greater rainfalls than do the lowlands, except the lowlands in the west, where rainfall is high. In the lowlands (below 1500m) rainfall is erratic and averages below 600mm. There is strong inter-annual variability of rainfall all over the country. Despite variable rainfall, which makes agricultural planning difficult, a substantial proportion of the country gets enough rain for rain fed crop production (Dinar et al, 2008).

1.2 Statement of the problem

Many research findings indicated that climate change have significant impacts on tropical regions, particularly poor countries are vulnerable to the harmful effect of climate change. The vulnerability of poor countries is due to their technological, resource and institutional constraints (Kurukulasuriya and Rosenthal, 2003).

Climate change is a global phenomenon. Its impact on agriculture in developing countries has been increasing. Some attempts have been made to estimate this impact (Dinar et al., 1998; Kumar & Parikh, 1998; Mendelsohn and Tiwari, 2000). The impact of climate change in Africa is a new area of research. A well known study in this respect is the one carried out under the Global Environmental Facility (GEF)-World Bank project entitled "**Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa**". This study covers the key agro-climatic zones and farming systems of the study countries (Kurukulasuriya and Mendelsohn, 2006). Although these attempts are increasing, not much research has been done on the likely impact of climate change on agricultural production and food security, energy, water resource, health, and ecosystem and wildlife.

Higher temperature and changing precipitation levels caused by climate change will depress crop yields. This is particularly true in low-income countries, where adaptive capacities are perceived to be low. Many African countries which have economies largely based on weather-sensitive agriculture are vulnerable to climate change. This vulnerability has been demonstrated by the devastating effects of recent flooding and the various prolonged droughts of the twentieth century. Thus, for many poor countries that are highly vulnerable, understanding farmers' responses to climatic variations and climate changes are crucial in designing appropriate coping strategies (Yesuf et al., 2008). Ethiopia which is dependent on rain-fed agriculture together with low level of socioeconomic development is highly affected and vulnerable to climate change.

There has been no much research on climate change impact with respect to Nile basin of Ethiopia. Moreover, the available few literatures on climate change impact on agriculture is not quite comprehensive particularly in terms of lack of economic assessment by considering climate, soil and socio-economic aspect of farmers. A known study for Ethiopia is done by Deressa (2006). His study was conducted using sub-regional (agro-ecology) agricultural data, not household-level data. Thus, the scale of his analysis ignores basic household-specific characteristics that are potentially the key to designing effective adaptation strategies.

Another limitation with Deressa's work is that it does not assess the effect of technology like irrigation which is used as an adaptation option to overcome the harmful effects of climate change. In addition to this, his study did not observe the impact of climate change on different farm activities such as irrigated and dry land farm separately. It only focused on the impact of climate change on agriculture (crop and livestock agriculture). However, the extent to which each of these activities responds to climate variables may be different. Therefore, a separate analysis is important for formulating effective policy.

This study tries to fill the existing research gap in the literature by examining the impact of climatic variables like temperature and precipitation on crop farming activities of irrigated and dry land farms separately (by assuming that the choice of either of these farming systems is exogenously determined). In addition, this study identifies choice for adaptation measure that farmers are using to mitigate potential climate impacts from expected changes in climatic conditions.

Lack of enough variation (spatial variation) on key climatic variables (precipitation and temperature) in cross-sectional data is one of the significant limitations in climate change impact studies. This is particularly true in developing countries, where one meteorological station set to cover a wide geographic area (Yesuf et al., 2008). To partially fill this gap, this study uses the climate data done by the thin plate spline method of spatial interpolation and imputes household-specific rainfall and temperature values using latitude, longitude, and elevation information for each household obtained from the survey.

1.3 Study objectives and research questions

The objective of the study is to analyze the effect of long-term climate change on agriculture and to identify the options for adaptation in Nile basin of Ethiopia.

The Specific aims of the study are:

i. to apply the Ricardian model with appropriate modifications to assess the extent of the relationship between agricultural income and climate variables;
ii. to determine the marginal impact of temperature and precipitation on agricultural income;
iii. to use the estimated Ricardian model to predict range of potential future impacts on agriculture under uniform climate change scenarios;

iv. to identify choices for adaptation measures that farmers are using to mitigate potential impacts from expected changes in climatic conditions.

Considering the findings of climate change impacts in other regions of the world, some relevant questions can be asked about climate changes and the response of crop agriculture in Nile basin of Ethiopia.

- What factors explain the vulnerability of the crop agriculture?
- What is the impact of climate change on agricultural profitability? Will crop agriculture profitable under future climate change scenarios?
- What long-term approaches should be recommended to maintain the adaptive mechanisms?

1.4 Significance of the study

Taken as a whole, this study assesses the potential economic impact of climate change and the options for adaptations, in order to provide a meaningful insight and contribute to efforts aimed at ensuring increased food availability through sustainable domestic production and increased income from agricultural production. Therefore, the study conducted on the basis of cross-district analysis and extrapolates the results to all districts in Nile basin of Ethiopia, and extended these to a national level economic analysis of the impacts of climate changes on agricultural production and adaptation strategies.

1.5 Scope and limitation of the study

One important limitation of this study is that it lumps all crops into one category i.e. general crop agriculture. Different crop types are affected differently by climate change, and hence the need for further disaggregation. Given that different crops have different climate requirements, future studies need to be focused on specific crop responses and adaptations, particularly crops which have long-term implications for food security in the region. This paper does not take into account revenue from livestock production, yet most farmers in Nile basin of Ethiopia combine livestock and crop production for subsistence.

Another shortcoming of this study springs from the nature of the household data used. Though there are data on long-term climate change, the full impact would be better assessed with time series data on crop production. Long-term changes in agricultural production may better reflect the impact of long-term climate change than one-time estimates of production. This cross-sectional study does not take into account water supply and availability in the analysis. The problem of water cannot be properly addressed without using a sophisticated hydrological–economic model.

Although this study does not examine the role of technological change, change in prices for the future and carbon fertilization effects, it does suggest some important conclusions regarding climate change impacts studies.

1.6 Organization of the paper

The rest of the paper is organized as follows. Chapter two reviews the literature. Chapter three is devoted to research methodology, functional form of the empirical models, dependent and independent variables, and data sources. Chapter four provides some statistical evidence on farmers' perceptions of and adaptations to climate change in the Nile basin of Ethiopia. Chapter five is all about econometric estimation, regression results and discussions. Chapter six concludes and suggests policy implications.

CHAPTER TWO

LITERATURE REVIEW

2.1 Approaches used to assess impact of climate changes on agriculture.

In this chapter an array of economic models that are used to assess impacts of climate change on agriculture are presented first (Mendelsohn & Dinar, 1999). Then empirical literature reviews on factors that affect crop net revenue or net revenue will be discussed. The chapter concludes with discussion of adaptations to climate changes.

2.1.1 Agro-ecological Zone (AEZ) Models

Agro-ecological zoning (AEZ) is also called crop suitability approach. It is used to assess the suitability of various lands and biophysical attributes for crop production. In this approach, crop characteristics, existing technology, and soil and climate factors, as determinants of suitability for crop production, are included (FAO, 1996). By combining these variables, the model enabled the identification and distribution of potential crop producing lands. As the model includes climate as one determinant of agricultural land suitability for crop production, it can be used to predict the impact of changing climatic variables on potential agricultural outputs and cropping patterns.

The AEZ method uses a simulation of crop yields, rather than measured crop yields. It is developed to look at potential production capacity across various ecological zones, not at what was actually occurring. In part, the reason for this focus on predicted values is the lack of reliable and accurate yield data on a widespread basis. Maximum potential yields for a given production area are estimated using a yield biomass simulation model.

A disadvantage of this modeling process is that one cannot predict final outcomes without explicitly modeling all relevant components. Even with relatively simple agronomic systems, it is difficult to build a general model that will predict actual yields across most locations. Just the omission of one major influence would damage the model's predictions (FAO, 2000). Although the AEZ model was not designed to perform economic analysis, economic variables may be linked into it through a linear optimization component. The inclusion of new technologies over time would have to be modeled and farmers' economic behavior would have to be integrated into the model. A serious new investment would be required for the AEZ model to be used as a predictive device in researching climate change.

2.1.2 Agro-economic models

The agronomic-economic approach is very similar to the one mentioned above. It begins with a crop model that has been calibrated from carefully controlled agronomic experiments (Kaiser et al, 1993; Kumar & Parikh, 2001; Rosenzweig & Parry, 1994). Crops are grown in the field or laboratory settings under different possible future climates and carbon dioxide levels. No changes are permitted to farming methods across experimental conditions so that all differences in outcomes can be assigned to the variables of interest (temperature, precipitation or carbon dioxide). The estimates do not include adaptation. The changes in yields are then entered into economic models that predict aggregate crop outputs and prices. Because each crop requires extensive experiments, only the most important crops have been studied to date. Almost all the agronomic studies have consequently focused on grains. A notable exception is the study by Adams et al. (1998) that includes not only grains but also citrus and tomatoes in order to account for more heat tolerant crops. Because the link between climate and crop yields is determined through controlled experiments, the crop modeling approach dependably predicts how climate affects yields. However, the experiments are

costly so only a few locations can be tested. This raises a question about whether the experiments are representative of the entire farm sector. In heavily tested areas, this may not be a serious problem. However, in developing countries there are only a few experimental sites and the results may not be generalizable. Further, the conditions in developing countries may require special adaptations such as irrigation that may or may not be included in the analysis (FAO, 2000).

2.1.3 Ricardian cross-sectional models

The Ricardian model is the common cross-sectional method that attempts to capture the influence of economic and environmental factors on farm incomes or land values (Mendelsohn et al., 1994). This model analyzes a cross-section of farms under different climatic conditions and examines the relationship between the value of land (Sanghi et al., 1998; Mendelsohn et al., 1994) or net revenue (Kumar and Parikh, 1998; Mendelsohn et al., 1994; Ouedraogo et al., 2006; Molua & Lambi, 2006; Kabubo-Mariara & Karanja, 2006; Eid et al., 2006; Benhin ,2006; Sene et al., 2006; Jain, 2006; Mano & Nhemachena, 2006; Deressa, 2006) and agro-climatic factors (Mendelsohn et al., 1994; Sanghi et al., 1998; Kumar & Parikh, 1998).

The Ricardian model has been applied to value the contribution of environmental factors to farm income by regressing farm performance (land values or net income) taken as dependent variables on a set of environmental factors, traditional inputs (land and labor) and support systems (infrastructure). These are independent variables in the model. Thus, the Ricardian approaches measures the contribution of each factor and detect the effects of long-term climate change on farm values (Mendelsohn et al., 1994; Mendelsohn & Dinar, 1999).

The Ricardian approach is a cross-sectional model which was named after David Ricardo (1772–1823) because of his original observation that land rents would reflect the net productivity of farmland (Mendelsohn & Dinar, 2003). It has been applied in the United States agriculture to study the impact of climate change using both net revenue and land value as dependent variable (Mendelsohn et al., 1994). Polsky and Esterling (2001) used land value as dependent variables in the United States to study the same.

In some developing countries such as Burkina Faso (Ouedraogo et al., 2006), Cameron (Molua & Lambi, 2006), Kenya (Kabubo-mariara & Karanja, 2006), Egypt (Eid et al., 2006), South Africa (Benhin, 2006 and Gbetibouo & Hassan, 2005), Senegal (Sene et al., 2006), Zambia (Jain, 2006), Zimbabwe (Mano & Nhemachena, 2006), Ethiopia (Deressa, 2006), Brazil (Sanghi, 1998), and India (Sanghi et al., 1998, Kumar & Parikh, 1998), the Ricardian approach has been applied to examine the sensitivity of agriculture to changes in climate. It was mainly used to assess economic impacts of climate change on agriculture in the above African countries by regressing net revenue (or crop net revenue) per hectare as response variable with climate (temperature and precipitation), hydrological, soils and socio-economic variables taken as explanatory variables.

Polsky (2004) and Mano and Nhemachena (2006) described that the value of a parcel of land in a well-functioning market system should reflect its potential profitability. This implies spatial variations in climate derive spatial variations in land uses and in turn land values. It should then be possible to estimate a meaningful relationship between climate and land value by specifying appropriate regression model. The estimated coefficients for the climate variables would reflect the economic value of climate to agriculture, holding other factors constant.

One of the advantages of the Ricardian model is its suitability to incorporate farmers' efficient adaptations by including relevant variables that reflect adaptations made by farmers to alter their operations in accordance with a changing climate. Farmers adapt to climate changes to maximize profit by changing crop mix, planting and harvesting dates, and a host of agronomic practices (Deressa, 2006). Mano & Nhemachena (2006) described crop choice as an important example of farmer adaptation strategies, where depending on the effects of warmer climate, a particular crop will be an optimal choice. Mendelsohn et al. (1994) also asserted the importance of optimal crop switching that must be considered when measuring the impact of climate change on agriculture.

The Ricardian cross-sectional approach is also used for a comparative assessment of with and without adaptation scenarios as used in the works of Ouedraogo et al. (2006) and Benhin (2006).The other advantage of the Ricardian model mentioned in Deressa (2006) is that it is cost effective in a sense that secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socioeconomic factors.

One of the weaknesses of the Ricardian approach is that it is not based on controlled experiments across farms. Farmers' responses vary across space not only because of climatic factors, but also because of many socio-economic conditions. Such non-climatic factors are seldom fully included in the model. Attempts have been made to include soil quality, market access and solar radiation to control for such effects (Mendelsohn et al., 1994; Kumar and Parikh, 1998). In general, however, it is often not possible to get perfect measures of such variables. Thus, not all of them may be taken into account in the analysis using the Ricardian method (Mendelsohn, 2000).

The fact that the model assumes constant prices is another drawback of the Ricardian approach (Cline, 1996). The inclusion of price effects in to it is problematic. The Ricardian

approach is weaker in this respect (Mendelsohn et al., 1994). Existing cross-sectional studies depend on a cross section within a country where there is little price variation across farms, with the result that the studies have not been able to estimate the effects of prices. The assumption of constant prices in Ricardian studies leads welfare calculations to be biased (Cline, 1996). The cross-sectional approach only measures the loss as producer surplus from climate changes. It takes no notice of price change that would occur if supply changed. As a result, it omits consumer surplus from the analysis. The result, according to Mendelsohn (2000), is that damages are underestimated (omit lost consumer surplus) and benefits are overestimated (overstate value of increased supply). Although Ricardian approach does not address the problem of inclusion of price effects, Mendelsohn et al. (1994) contend that the bias is less than 7 percent.

Moreover, there are also many arguments for the difficulty to include price effects using any method (Mendelsohn and Tiwari, 2000). First, it is the global markets that determine the prices of most crops. Therefore, prediction of what would happen to each crop requires global crop models. It is difficult to predict what will happen to the global supply of any single crop in a new world climate since global crop models are poorly calibrated. Secondly, Reilly et al. (1994) pointed out that the range of warming expected for the next century has only small effect on aggregate supply. This result is obtained from the few global analyses completed so far. Finally, if aggregate supply changes by only moderate amount, the bias from assuming constant prices is relatively small. Thus, Mendelsohn and Tiwari (2000) argue that keeping prices constant is justified because it does not pose a serious problem in using the model. The other argument, based on Kurukulasuriya & Rosenthal (2003), is that this weakness also applies to all agro-economic models.

The reality that the model does not take into account the fertilization effect of carbon dioxide concentrations is another weakness of the model (Cline 1996; Mendelsohn and Tiwari, 2000). However, regardless of these weaknesses, it can be used to analyze the impact of climate change on agriculture by fully considering adaptations farmers make to mitigate the harmful effects of the change (Deressa, 2006).

2.2 Empirical Literature Review

There are four ways that climate would have a physical effect on crops (Kurukulasuriya and Rosenthal, 2003). Changes in temperature and precipitation directly affect crop production and can even alter the distribution of agro-ecological zones. Secondly, increased carbon dioxide is expected to have a positive effect on agricultural production due to greater water use efficiency and higher rates of plant photosynthesis. Thirdly, runoff or water availability is critical in determining the impact of climate change on crop production, especially in Africa. Finally, agricultural losses can result from climate variability and the increased frequency of changes in temperatures and precipitation (including droughts and floods).

Kurukulasuriya and Rosenthal (2003) state that in middle and higher latitudes, higher temperature will lengthen growing seasons and expand crop producing areas pole-ward, thus benefiting countries in these regions. In contrast, in lower latitudes, it is expected that higher temperature will adversely affect growing conditions, especially in areas where temperature close to or at optimal level for crop growth to begin with.

Ouedraogo et al. (2006) examined the impact of climate change on agriculture. Results from their study indicated that the relationship between net revenue and temperature and precipitation is non-linear. This means that temperature or precipitation affects net revenue positively up to a certain limit, above which it causes damage to crops. The above authors

showed that a 1^0C temperature increase will decrease net revenue by US$19.9 per hectare. But 1mm/month precipitation increase will increase revenue by US$2.7 per hectare.

By using Intergovernmental Panel on Climate Change (IPCC) uniform climate scenarios, they also showed that an increase in temperature and a decrease in precipitation are critical for crop yield in Burkina Faso. For example, an increase in temperature of 5^0C will be very harmful for agriculture. At this temperature farms would lose 93% of their net revenues obtained from crops. Farmers would also lose their entire net revenue from crops if precipitations decreased by 14%. Molua and Lambi (2006) also showed that net revenues will fall when precipitation decreases or temperature increases across farms in Cameron.

Kabubo-Mariara & Karanja (2006) study the economic impact of climate change on Kenyan crop agriculture. Their results showed that climate affect agricultural productivity. The result further showed that increased winter temperature associated with higher crop revenue, but increased summer temperature has a negative impact. Increased precipitation is positively correlated with net crop yield.

The estimated marginal impacts of climate variables (temperature and precipitation) revealed that global warming is harmful for agricultural productivity i.e. the temperature component of global warming is much important than precipitation for crop agriculture in Kenya. Kabubo-Mariara & Karanja (2006) confirmed this result by various climate change scenarios on agriculture. The two Global Circulation Models (GCM) used for their study are Canadian Climate Change (CCC) and Geophysical Fluid Dynamics Laboratory (GFDL) models which predicts 3.5^0C and 4^0C changes in temperature by the year 2030 respectively. Both models predict a 20% change in precipitation over the same period. The prediction results confirmed that global warming will have a substantial impact on crop net revenue. These conditions are pronounced more in medium and low potential zones than in high potential zones. Based on

the CCC model, they predicted a 1% (US$3.54 per hectare) gain in high potential zones but a 21.5% (US$54 per hectare) loss in medium and low potential zones. The GFDL model predicted a loss of US$32 per hectare in the high potential zones compared to losses of US$178 per hectare in medium and low potential zones by the year 2030.

Fischer and Velthuizen (1996) and Downing (1992) also studied the impact of climate change on Kenya. They found that higher temperature would have positive impact in highland areas. Downing (1992), used a model of land use to estimate changes in availability of land suitable for cropping, has shown that in highland areas of western Kenya, there is likely to be a 67 percent increase in high potential land in response to a 2.5° C rise in average temperature. In contrast, rising ambient temperatures may have a detrimental effect in many lowland areas, particularly those that are semiarid.

Eid et al. (2006) assessed the economic impacts of climate change on agriculture in Egypt. They developed and estimated four different Ricardian models. With respect to the standard Ricardian model, results showed that an increase in temperature of 1^0C would reduce net revenue by US$968.94 per hectare without livestock and US$1044.28 per hectare with livestock. In the second model including irrigation in the analysis reduces the harmful effect of increased temperature. In this model, net revenue increased by US$26.17 per hectare without livestock. Net revenue reduced by US$1680.14 per hectare when livestock is included. In the third model, they included linear and quadratic terms of flow. In this case net revenue increased by US$150.96 per hectare without livestock and decreased by US$1412.41 per hectare when livestock is included. Finally, increased net revenue by US$77.78 and US$1837.17 per hectare is expected without and with livestock respectively when heavy and light machineries included in the analysis.

Benhin (2006) studied economic impacts of climate change on crop farming activities. He examined how long-term farm profitability varies with local climate such as temperature and precipitation, while controlling other factor in South Africa. Models were estimated for different farming systems. Marginal impact analysis from his study indicated that all farming systems under consideration will experience positive annual crop net revenue impacts from increased precipitation except the small-scale farms. An increase in crop net revenue of US$2 for the whole country, US$29 for irrigated farms, US$20 for dry land farms and US$25 for large-scale farms, but a fall of US$28 for small-scale is expected with a 1mm/month annual increase in precipitation.

Benhin (2006) used climate scenarios for South Africa. These climate scenarios indicated that temperature will increase by 2.3^0C and 9.6^0C while precipitation will decrease by 2% and 8% in 2100. Using these values of temperature and precipitation, the study predicted that crop net revenue will fall by as much as 90% by 2100, small scale-farms being most affected.

Two Ricardian approach studies in South Africa which are contradictory in their finding were done by Deressa et al. (2005) and Gbetibouo and Hassan (2005) independently on the economic impact of climate change on sugarcane production and major South African field crops respectively. The former employed a time series analysis. This analysis showed that climate change has non-linear impacts on net revenues with low sensitivity to future increase in precipitation than in temperature. Moreover, they also find that an increase in temperature of 2^0C (which is caused by doubling of carbon dioxide) and precipitation by 7% would have a negative impact on sugarcane production in South Africa. The latter authors tried to analyze the economic impact of climate change on major field crops. They found that field crops are less sensitive to marginal changes in precipitation than changes in temperature comparatively. Irrigation is an effective adaptation measures to the harmful effect of climate change on field

crops in this analysis but Irrigation do not provide an effective option for reducing climate change impacts in sugarcane production: two contrary finding in South Africa.

Sene et al (2006) examined the economic impact of climate change on small farmers' net revenue. In their study small rain fed farms are highly vulnerable to climate change. They observed the impact of an increase in temperature of $1.5^{o}C$ combined with 8.5% decrease in rainfall in the one hand and the same increase in temperature and a 17% decrease in rainfall on the other hand. These simultaneous changes in temperature and rainfall indicated that farm net revenues will be affected by further increase in temperature and decrease in rainfall. The implication of these results is that agricultural production in Senegal could be affected by high temperature and low rainfall.

Mano & Nhemachena (2006) showed that agricultural productions of smallholder farming system are significantly constrained by high temperature and low precipitation. Their study tried to see the impact of SRES (Special Report on Emissions Scenarios) climate change scenarios specifically using CGM2 (Canadian Global Climate Model 2), HadCM3 (Hadley Centre Climate Model 3) and PCM (Parallel Climate Model). Farm net revenues will decrease by US$0.8 billion using CGM2, US$1.3 billion using HadCM3 and US$1.4 billion using PCM in Zimbabwe.

According to Deressa's study (Deressa, 2006) for Ethiopia, both increasing temperature and decreasing precipitation are damaging Ethiopian agriculture. This conclusion is based on marginal impact analysis (increasing temperature and precipitation across the four seasons such as winter, spring, summer and fall), impact of uniform and SRES climate scenarios. Deressa's (2006) marginal impact analysis indicated that net revenue would reduce by US$177.62 and US$464.71 per hectare with increasing temperature during summer and winter respectively. Net revenue increased by US$225.09 during spring with increasing

precipitation. Secondly, the impact of uniform climate scenarios on net revenue per hectare of Ethiopian farmers examined via increasing temperature by 2.5^0C and 5^0C and decreasing precipitation by 7% and 14%. In these scenarios, increasing temperature appeared to be less harmful than decreasing precipitation. His empirical evidence indicated that decreasing precipitation and increasing temperature by 14% and 5^0C reduced net revenue by US$0.39 and US$0.00016 correspondingly, which is very small compared to this study findings (see chapter five for more details). Finally, the results of the predicted impacts from the SRES models for the next five and ten decades indicated that there would be a positive net revenue impact though this net impacts in all cases are very small.

2.3 Adaptations to climate changes

Adaptation to climate change impacts in general and to the agriculture sector in particular is an existing phenomenon. The agriculture sector has the capacity to adapt provided that technologies, resources, and management changes have been undertaken relatively quickly (Mendelsohn, 2000).

Throughout human history, societies have adapted to natural climate variability by altering settlement and agricultural patterns and other facets of their economies and lifestyles. In the past human history, adaptations to climate have been remarkably successful. Scholars in the field characterized human beings as the most adaptable of animal species. Coping with climate has not always been easy or successful as the records of collapsed societies reveal and there are still limits to adaptations. This long record of adapting to impacts of weather and climate is through changes in behavior, choices of technology and infrastructure, use of market instruments and public policies. Crop diversification, weather and seasonal climate forecasting, drought and hurricane early warning systems, flood protection, weather derivatives, and establishment of coastal-setbacks are only a few examples of proactive

adaptation measures. Adaptation can be reactive such as emergency response, disaster recovery, and even migration (Kurukulasuriya and Rosenthal, 2003).

Decisions on the type of adaptation are often made by individuals, groups within society, and organizations and governments on behalf of society. Some adaptation measures may be taken at individual level. Others like rainwater harvesting and investments, building dams, releasing new cultivars that are more drought resistance require collective actions. These time societies have inherent capacities to adapt to climate change and have developed different adaptation and mitigation strategies to combat climate change. They have developed knowledge, skills, technology, institutional arrangements and strategies that are important foundations for adapting to long-term climate change. Based on the type of economic activities and social networks societies can access local coping strategies against shocks. These highly differ among households and communities. Communities have always adapted to climate variations by making preparations based on their resources and knowledge accumulated through experience of past weather pattern. The adaptive measures that households use when faced with climate change could also differ in terms of their ease of implementation, equity effects, lag between implementation and effect, their cost of implications, compatibility with other programs, and agencies implementing measures (Admassie, 2008).

The capacity to adapt to climate change also varies across countries, social groups and regions over time. These capacities will depend to a large extent on the availability of natural resources, their level of development, their resource base, technological knowhow and level of information about climate change, and their scientific & technical capacity. Greater economic resource availability increases adaptive capacity while the lack of it limits adaptation options. Technological options limit range of potential adaptation choices. Hence, adaptation measures are very much related to socio-economic conditions of the country and community given basic forms of adaptations including micro-level adaptations such as

diversification and intensification of crop and livestock production, changing land use, irrigation and altering the timing of operations, market responses, institutional changes and technological developments (Kabubo-Mariara & Karanja, 2006; Darwin et al, 1995).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 The Ricardian Method/Approach

The Ricardian method is a cross-sectional approach to studying 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 & Dinar, 2003):

Assuming the existence of a set of well-behaved production function of the form:

$$Q_i = Q_i(K_i, E), i = 1, 2, ..., n \quad \ldots\ldots (1)$$

Where: Q_i = is the quantity of the product of good i

$K_i = (k_{i1}, k_{i2}, ..., k_{ij}, ...k_{iJ})$ is a vector of all purchased inputs j used to produce Q_i, k_{ij} = the purchased input j $(1, 2, ..., J)$ in the production of good i.

$E = (E_1, E_2, ..., E_m, ..., E_M)$ is a vector of site specific exogenous environmental factors such as climate(temperature and precipitation) and soil.

Given a set of factor prices w_j, E and Q, cost minimization provides the cost function of the form:

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

Where: C_i is the cost of production of good i and $W(w_1, w_2, ..., w_n)$ is a vector of factor prices.

Using the cost function C_i at a given market prices, the profit maximization by farmers on a given site can be specified as

$$Max(\pi) = P_i Q_i(K_i, E) - C_i(Q_i, W, E) - P_L L_i \quad \ldots\ldots (3)$$

Where: P_L is the annual cost or rent of land at that site, L_i is the land in hectare.

Under perfect competition all profits in excess of normal returns to all factors (rents) are driven to zero i.e.

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

If the production of good 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 good. Solving equation (4) for P_L gives the land rent per hectare to be equal to net revenue per hectare.

$$P_L = (P_i Q_i^*(K_i, E) - C_i^*(Q_i^*, W, E)) / L_i \quad \ldots\ldots (5)$$

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

$$V_L = \int_0^\infty P_L e^{\sigma t} dt \quad \ldots\ldots (6)$$

$$= \int_0^\infty [(P_i Q_i^*(K_i, E) - C_i(Q^*, W, E)) / L_i] e^{\sigma t} dt \quad \ldots\ldots (7)$$

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 affects farm value. The model uses actual observations of farm

performance in different agro-climatic zones (Mendelsohn et al., 1994). The standard Ricardian model relies on a quadratic formulation of climate:

$$V = B_0 + B_1 F + B_2 F^2 + B_3 Z + B_4 G + u \quad \ldots\ldots (8)$$

Where:

F = vector of climate variables

Z= set of soil variables

G= set of socio-economic variables

u= an error term

F and F^2 capture linear and quadratic terms for temperature and precipitation. The introduction of quadratic terms for temperature and precipitation reflects the 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 the quadratic term is negative, the function is hill shaped. For each crop, there is known temperature where that crop grows best across the seasons though the optimal temperature varies from crop to crop (Mendelsohn et al., 1994).

Given equation (8) one can derive the marginal impact of climate variables (f_i) on crop revenue evaluated at the mean as follows:

$$E[\frac{dV}{df_i}] = E[B_{1,i} + 2B_{2,i} * f_i]$$

$$= B_{1,i} + 2 * B_{2,i} * E(f_i) \quad \ldots\ldots (9)$$

The change in economic welfare, ΔW, resulting from an environmental change from A to B, which causes environmental inputs to change to E_B can be measured as follows (Kurukulasuriya and Mendelsohn, 2006). Here one can analyze the impact of exogenous changes in environmental variables on net economic welfare (ΔW). The net economic welfare is the change in welfare induced or caused by changing environment from a given state A to B, which causes environmental inputs to change from E_A to E_B. The change in annual welfare from this environmental change is given by:

$$\Delta W = W(E_B) - W(E_A)$$

$$= \int_0^{Q_B} [(P_i Q_i(K_i, E_B) - C_i(Q_i, W, E_B)) / L_i] e^{\sigma t} dQ - \int_0^{Q_A} [(P_i Q_i(K_i, E_A) - C_i(Q_i, W, E_A)) / L_i] e^{\sigma t} dQ . (10)$$

If market prices do not change as a result of the change in E, then the above equation reduced to:

$$\Delta W = W(E_B) - W(E_A)$$

$$= [PQ_B(K_i, E_B) - \sum_{i=1}^{n} C_i(Q_i, W, E_B)] - [PQ_A(K_i, E_A) - \sum_{i=1}^{n} C_i(Q_i, W, E_A)] \ldots\ldots\ldots\ldots (11)$$

Substituting for $P_L L = P_i Q_i^* - C_i(Q_i^*, W, E)$ from (5)

$$\Delta W = W(E_B) - W(E_A) = \sum_{i=1}^{n} (P_{LB} L_{Bi} - P_{LA} L_{Ai}) \ldots\ldots\ldots\ldots (12)$$

Where P_{LA} and L_A are at E_A and P_{LB} and L_B are at E_B.

The present value of welfare change in thus

$$\int_0^{\infty} \Delta We^{\sigma t} = \sum_{i=1}^{\infty} (V_{LB} L_{Bi} - V_{LA} L_{Ai}) \quad \ldots\ldots (13)$$

The Ricardian model takes either (12) or (13) depending on whether data are available on annual net revenues or capitalized net revenues (land values, V_L). The model in (12) was employed for this study to measure the impact of climate change in Nile basin of Ethiopia, as data on land prices for the selected samples were not available. This approach have been applied by Sanghi et al. (1998) and Kumar & Parikh (1998) for India, Deressa (2006) for Ethiopia, Ouedraogo et al. (2006) for Burkina Faso, Molua & Lambi (2006) for Cameron, Kabubo-Mariara & Karanja (2006) for Kenya ,Eid et al.(2006) for Egypt, Benhin (2006) for South Africa, Sene et al. (2006) for Senegal, Jain (2006) for Zambia and Mano & Nhemachena (2006) for Zimbabwe[1].

3.2 Model Specification

The empirical models developed for this study follow the works of Mendelsohn et al. (1994), Sanghi et al. (1998), Ouedraogo et al. (2006) and taking into account the climate in Nile basin of Ethiopia. The models examine how long-term farm profitability varies with climate (temperature and precipitation) and soils while controlling for other factors. Relevant socio-economic variables are also assessed to see the extent to which they control or worsen the adverse impacts of climate change on crop agriculture. Two main models are formulated: 'without' adaptation and 'with' adaptation. The former include only climate and soil variables, while the latter in addition to these variables include relevant socio-economic variables such as whether the farm irrigated, cropland area, livestock ownership, distance to nearest market for obtaining inputs and selling products, access to formal extension, farm to

[1] This methodology has been applied in Canada since in 1970.

farm extension, access to formal credit, household size, years of education of the household head and farming experience. These two models estimated for sample farms that represent Nile basin of Ethiopia (here after called full sample model or entire farm model), irrigated and dry land farms to assess any significance difference in the impacts of climate change on these different farming systems. The descriptive statistics for the above socio-economic variables and other variables used in the regression are presented in Table A-1, Table A-2 and Table A-3 in the annex.

The model without adaptation options includes only the physical variables (temperature, precipitation and soils):

$$NR\_1\backslash ha = B_0 + B_1 sum\_t + B_2 sum\_t^2 + B_3 win\_t + B_4 win\_t^2 + B_5 spr\_t + B_6 spr\_t^2 + B_7 fal\_t + B_8 fal\_t^2 + B_9 sum\_p + B_{10} sum\_p^2 + B_{11} win\_p + B_{12} win\_p^2 + B_{13} spr\_p + B_{14} spr\_p^2 + B_{15} fal\_p + B_{16} fall\_p^2 + \sum_{i=1}^{n} \Delta_i soil_i + E_k^1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Model1$$

The model with adaptation includes the previous variables and farms characteristics:

$$NR\_2/ha = B_0 + B_1 sum\_t + B_2 sum\_t^2 + B_3 win\_t + B_4 win\_t^2 + B_5 spr\_t + B_6 spr\_t^2 + B_7 fal\_t + B_8 fal\_t^2 + B_9 sum\_p + B_{10} sum\_p^2 + B_{11} win\_p + B_{12} win\_p^2 + B_{13} spr\_p + B_{14} spr\_p^2 + B_{15} fal\_p + B_{16} fal\_p^2 + \sum_{i=1}^{n} \Delta_i soil_i + \sum_{j=1}^{m} \Omega_j X_j + E_k^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots Model2$$

Where: sum_t, win_t, spr_t and fal_t are the mean long-term weather temperature for the summer, winter, spring, and fall season respectively, and sum_p, win_p, spr_p, and fal_p are the mean long-term weather precipitation for summer, winter, spring, and fall season respectively. The variables X_j are set of socio-economic variables and the B, Δ, and Ω are coefficients of the seasonal temperature & precipitation, soils and socio-economic variables respectively. E_k^1 and E_k^2 are the random disturbance term for the first and second model respectively.

It is not obvious how to represent monthly temperature and precipitation data when Ricardian regression model is applied (Kurukulasuriya & Mendelsohn, 2006). The correlation between adjacent months is too high to include every month. This study explored several ways of defining three-month average seasons. Comparing the results, defining summer (the average for June, July and August), winter (the average for December, January and February), spring (the average for March, April and May) and fall (the average for September, October and November) provided the most robust results for Nile basin of Ethiopia.

The independent variables include the linear and quadratic terms of temperature and precipitation and only linear terms of soils and farm characteristics.

3.3 Description of dependent and independent variables

3.3.1 Crop net revenue per hectare

The dependent variable (V) indicated in equation 8 is measured as crop net revenue per hectare of cropland. Crop net revenue for this study is gross crop revenue which is the product of total harvest and price of the crop (the value of crop production) less total associated cost of production calculated for each agricultural household. The total harvest of the crops includes harvest used for household consumption, livestock feed and harvest sold. The total cost is the total variable cost (TVCs) which includes expenditure on transport, packaging, marketing, storage, post-harvest losses, fertilizer, pesticide, seeds, labor, and other depreciation costs of the use of light and heavy machinery. Other costs included are rent paid on cropland and interest paid on loans. This study tries to exclude the cost of household labor for various reasons. Taking into consideration of household labor costs led to negative net incomes, which can be explained as the effect of over estimating the working hours which in turn determining these is problematic in family agriculture, as reported in the agricultural

literature (Bardhan & Urdry, 1999). This study therefore defined crop net revenue without household labor cost and controlled for the effect of household labor by including household size as a proxy for it as dependent variable in the estimation model.

3.3.2 Climate variables: temperature and precipitation

This data (temperature and precipitation) were constructed from weather station using interpolation into areas where observations are missing for each month of the survey year period (2004/2005). Mendelsohn et al. (2004) reveal that weather stations give accurate measures of ground conditions. These monthly means were estimated from approximately 50 years of data (1951–2000) to reflect long-term climate changes rather than short-term variations. Ideally, the temperature and precipitation data for the 50 years leading directly up to 2004/05 would be used, but because longer-term trends are of interest, and because climate change is most drastic in the longer run, using data from 1951–2000 rather than from 1951-2004 should not be of much practical concern.

3.3.3 Soils variables

Different soil types are included in the study. These soils are sandy, clay, dark, red, and dark red. One should note that although these soils seem to be more prominent in Nile basin of Ethiopia this does not imply that they are also important for crop farming activities. The expected effect of these soils will depend on the type of the soil.

3.4 Data sources and description of the study area

3.4.1 Data sources

The analysis for this study uses data at the household levels on farm activities, climate, soils and socio-economic information. These three sets of data are discussed below.

Farm household data: Farm household data were obtained from a cross-sectional household survey of farmers carried out during the 2004/05 production year in Nile Basin of Ethiopia by Environmental Economics Policy Forum for Ethiopia (EEPFE), Ethiopian Development Research Institute (EDRI) in collaboration with International Food Policy Research Institute (IFPRI) to analyze the potential impact of climate variability and climate change on household vulnerability and farm production. The household survey covered five regional states of Ethiopia. These are Amhara, Oromiya, Benishangul-Gumuz, Tigray, Southern Nation Nationalities and People (SNNP), 20 districts, and 1000 households. The sample districts were purposely selected to include different attributes of the basin such as traditional topology of agro-ecological zones in the country (*Kolla, Woina Dega, Dega, Bereha*), the degree of irrigation activity (percent of cultivated land under irrigation), average annual rain fall, rain fall variability (coefficient of variation for annual rain fall), and vulnerability.

One peasant association was selected from each district making a total of 20 by purposive sampling method to include households that irrigate their farms. Once the peasant associations were chosen, 50 farmers were selected at random from each peasant association, making, 1,000 which is the total number of population (See Deressa et al., 2008 and Yesuf et al., 2008 for details).

The questionnaire for this survey attempted to capture information on the pertinent variables required to calculate crop net revenues and to explain the variation in net revenues across

representative sample districts, and agro-climatic regions. The questionnaire is intended for households that have harvested any crops or sold any livestock in 2004/05 production year.

The questionnaire has nine main sections. Section one focused mainly on household's characteristics-members of households, education, and employment while section two focused on household assets, basic services, disease and shock. Section three is about land tenure. Section four is about farm machinery, farm buildings, wells and pumps etc. The questions in section five and six are mainly about crop production- annual and perennial crops and livestock production respectively. Detailed information was obtained on crop farming activities with respect to the types of crops grown, the area of land planted, the amount of harvested and sold and other crop farming related costs such as seeds, fertilizer and pesticides, light and heavy machinery and farm animal power as well as on livestock and poultry products, such as milk, beef, eggs, and wool. Section seven is about farmers' access to credit, market and extension. Section eight is about expenditure on food and expenditure. Finally, section nine is about perceptions of climate change and adaptation options farmers used.

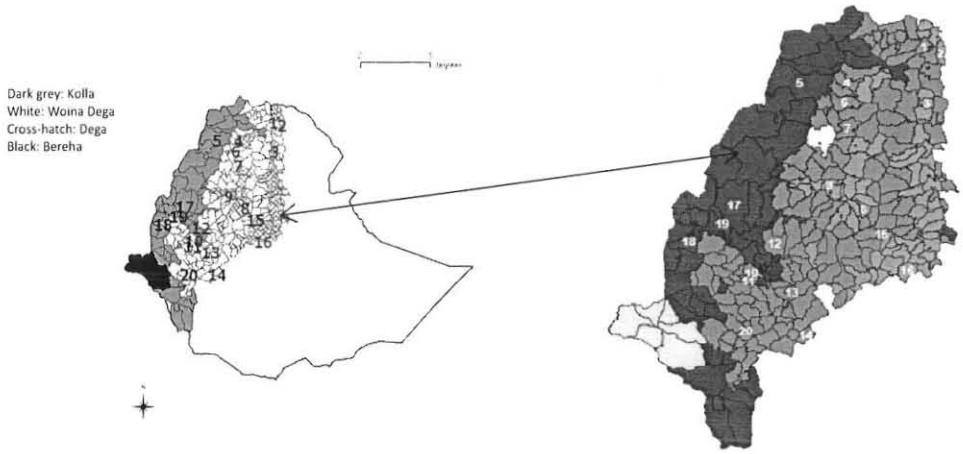
Climate data: These were obtained from the same survey mentioned above. The temperature and precipitation data for each district comes from the same source. Some of the study districts have their own metrological stations while others have no such metrological station to measure both temperature and precipitation. Therefore, this study uses the data done by the thin plate spline method of spatial interpolation and imputes household-specific rainfall and temperature values to correct this limitation (Yesuf et al., 2008).

Soil Data: the soil data for this study comes from the same survey mentioned above.

3.4.2 Description of the study area

The study area (Nile basin of Ethiopia) covers a total of about 358,889 Km^2-equivalent to 34% of the total geographic area of the country. Around 40% of the population of Ethiopia lives in this basin. The basin covers the six regional states of Ethiopia in different proportion: 38% of the total land of Amhara, 24% of Oromiya, 15% of Benishangul-Gumuz, 11% of Tigray, 7% of Gambella, and 5% of Southern Nation Nationalities and Peoples (SNNP).

The Abay River, which originates in the central highlands; Tekkezze River, which originates in the northwest; and the Baro-Akobo River, which originates in the southwestern, are the major rivers in the Nile basin of Ethiopia. They provide an estimated total annual surface runoff amounting to 80.83 billion cubic meters per year. This number is approximately equivalent to 74% of Ethiopia's 12 river basins (MoWR, 1998; Deressa et al., 2008). The study area with its traditional agro-ecological zones is shown below.



Source: Deressa et al. (2006)

Note-1 Districts surveyed in Nile basin of Ethiopia are: 1=Hawzen, 2= Atsbi wonberta, 3=Endamehoni, 4=Debark, 5=Sanja, 6=Wogera, 7=Kemkem, 8=Enemay, 9=Quarit, 10=Gimbi, 11=Haru, 12= Limu, 13= Nunu kumba, 14=Kersa, 15= Hindabu Abote, 16=Bereh Aleltu, 17=Wombera, 18=Bambasi, 19=Sirba Abay and 20=Gesha Daka

Note-2: Kolla, Woina Dega, Dega and Bereha are coloured with blue, green, red and grey respectively.

Figure-1: Map of traditional agro-ecological zones and woredas selected for sample in Nile Basin of Ethiopia

CHAPTER FOUR

DESCRIPTIVE STATISTICS

4.1 Farmers' perceptions of and adaptation to climate change.

This section analyzes farmers' perceptions of climate change and adaptation methods developed and implemented by farmers in Nile basin of Ethiopia. Moreover, this section presents the outcome of the survey of farmers' constraints in their farming practices in response to climate changes.

4.1.1 Farmers' perception of changes in the climate

The survey instruments were designed to capture farmers' perceptions and understanding of climate change as well as their approaches to adaptations. The farmers were asked whether they have noticed changes in mean temperature and rainfall. Results show that 53% of the selected households have perceived changes in the mean temperature while the corresponding response to rainfall accounts for 76% in the last two decades.

Regarding the direction of the change in temperature, 67% of the sample households perceive an increase in mean temperature and 4% a decrease. The rest (29%) do not know the direction of the mean change in temperature. With regard to the rains, 18% of the sample household observed an increase and 62% a decrease while 20% of them do not observe any change. Table 4.1 depicts farmers' perceptions of climate changes. In general, increased temperature and declined precipitation are the predominant perceptions in the study sites.

Table-4.1: Households' perceptions on climate change over the past 20 years (percentages).

Number	Directions	Temperature	Precipitation
1.	Increase	67	18
2.	Decrease	4	62
3.	Same	29	20
Total		100	100

Source: **EEPFE, EDRI-IFPRI survey data (2004/2005) and own calculation**

4.1.2 Adaptations to climate change

In Nile basin of Ethiopia, farmer's ability to adapt is limited by their lack of economic and technical resources, and their vulnerability is accentuated by heavy dependence on the climate, because of the rain fed system, diseases (malaria) and their poverty. Given the diversity of the constraints they have to face, the general capacity to adapt to climate changes is currently very low. There are no good national action plans which take into account short or long term climate changes.

The effects of the climate variations and climatic constraints in Nile basin of Ethiopia are numerous. The climate change is associated with the source of difficulties in the rural world. The prolonged and increasing temperature, combined with the declining of the rain fall and the frequency of the drought, as well as the marked degradation of the soils, have resulted in a succession of bad crop years. Deressa et al. (2008) indicated that crop yield declined by 32.8% as result of shocks such as drought, hailstorm, and flood etc. Farmers therefore try to develop their own strategies to mitigate climate impacts.

The adaptation methods most commonly cited in the literature include the use of new crop varieties and livestock species that are more suited to drier conditions, irrigation, crop diversification, mixed crop livestock farming systems, changes of planting dates, diversification from farm to nonfarm activities, increased use of water and soil conservation techniques, and trees planted for shade and shelter (Nhemachena and Hassen, 2007).

In the case of Nile basin of Ethiopia farmers were asked about their perceptions of climate change and their actions to counteract the negative impact of climate change. The adaptation measures that farmers report may be profit driven, rather than climate change driven. Therefore, one can assume that their actions are driven by climatic actions, as reported by farmers themselves (Nhemachena and Hassen, 2007). As shown in Table 4.2, about 58% of the farmers did at least something in response to climate changes. This shows that they are aware of the changing climatic conditions. Most farmers did not use any adaptation option (42%) for a number of reasons (see section 4.1.3). The adaptation strategy most commonly used (about 21%) is planting trees. Other adaptation strategies farmers used are soil conservation (15%), using different crop varieties (13%), early and late planting (5%) and irrigation (4%)

Table-4.2: Adaptation methods in the study site

Number	Adaptation methods	Percentages
1.	No adaptations	42
2.	Planting trees	21
3.	Soil conservations	15
4.	Different crop varieties	13
5.	Early and late planting	5
6.	Irrigations	4
Total		100

***Source*: EEPFE, EDRI-IFPRI survey data (2004/05) and own calculation**

This greater use of planting trees is mainly ascribed to provide natural shades for their livestock or as a wind or hail storm break when the temperature is hot. Soil conservation techniques may be attributed to avoid the risk of flooding. The use of different crop varieties as an adaptation method could be associated with the lower expense and ease of access by farmers. The low use of early and late planting adaptation mechanism may be put down to inadequate information service to ensure that farmers receive up to date information about rainfall and temperature patterns in the forthcoming seasons. The limited use of irrigation could be attributed to the need for more capital and low potential for irrigation. However, most of the farmers do not have any of these adaptation strategies mainly because of lack of necessary funds, information and government support.

Table 4.3 presents the most commonly observed responses of farmers towards temperature and precipitations changes: 56.8% of the selected households have no adaptation strategy to face an

increase in temperature, 20% changed crop varieties, and 13.3% planted trees, 2.9% put into practice soil conservation techniques and others (about 7%).

Regarding adaptation to change in rainfall patterns, about 42% have no adaptation strategy. Soil conservation schemes (30.4%) is the strategy most commonly adapted. The use of different varieties of crops (11.1%) is another strategy adopted by farmers. Planting early and harvesting water are another adaptation strategies each accounts 4.1%. Others constitute about 8.3% (see Table 4.3)

Table-4.3: Adjustments made to long-term shifts in climate change (temperature and precipitation)

Adaptation methods	Percentages
	Temperature
No adjustment	56.8
Changed crop varieties	20.0
Planted trees	13.3
Soil conservation techniques	2.9
Others*[2]	7.0
	Precipitation
No adjustment	42.0
Soil conservation techniques	30.4
Changed crop varieties	11.1
Planted early	4.1
Harvested water	4.1
Others**[3]	8.3
Total	200

***Source*: EEPFE, EDRI-IFPRI survey data (2004/05) and own calculation.**

[2] Others refers to the following adaptation methods: planted early, used irrigations, sold livestock, sought off-farm activities, planted late, harvested water, migrated to urban area, changed farming type from crop to livestock, and adopted new technologies.

[3] Others refers to the following adaptation options such as planted trees, planted early, used irrigations, sold livestock, sought off-farm activities, planted late, migrated to urban areas, changed farming type from crop to livestock, and new technologies.

The information from Table 4.2 and Table 4.3 is very important in terms of policy for agricultural management. The decision makers should integrate the strategies actually adopted by farmers to help in the improvement of agriculture. The development of research to create new varieties adapted to climate context should be given a high priority attention. Given the high percentage of households without any adaptation, the government should develop a strong system for the provision of information and sensitization of farmers to show them the importance of having strategies for adaptation to climate change.

4.1.3 What are the constraints on adapting?

Summary statistics indicate that there are five major constraints to adaptation in Nile basin of Ethiopia. These are lack of information (43%), lack of access to credit (22%), shortage of labor (16%), shortage of land (11%), and poor potential for irrigations (8%). Table 4.4 shows the major constraints to adaptation perceived by farmers in the basin.

Table-4.4: Barriers to adaptations

Constraints	Percentages
Lack of information	43
Lack of money	22
Shortage of labor	16
Shortage of land	11
Poor potential for irrigations	8
Total	100

Source: **EEPFE, EDRI-IFPRI survey data (2004/05) and own calculation**

Most of these constraints are associated with poverty. Lack of information on appropriate adaptation options could be attributed to scarcity of research on climate change and adaptation options. Lack of money hinders farmers from getting the necessary resources and technologies that facilitates adapting to climate change. If farmers do not have sufficient family labor or financial means to hire labor, they can not adapt. This is true since adaptation to climate change is costly. Shortage of land has been associated with high population pressure, which forces farmers to intensively farm a small plot of land. Poor irrigation potential is most likely associated with the inability of farmers to use the water that is already there due to technological incapability. The reasons of farmers not doing the farm level adaptations options are illustrated in Table 4.5. Lack of information is the prominent constraints.

Table-4.5: Constraints to farm-level adaptations

Lack/shortage	Changing crop varieties	Water harvesting	Soil conservations	Planting trees	Irrigating
Information	52.0	41.0	47.0	42.0	24.0
Money/credit	36.0	27.0	11.0	9.0	27.0
Labor	3.0	18.0	26.0	17.0	16.0
Land	4.0	3.0	2.0	18.0	10.0
Water	0.2	1.0	1.0	1.0	15.0
Others***[4]	4.8	10.0	13.0	12.0	8.0

***Source*: EEPFE, EDRI-IFPRI survey data (2004/05) and own calculation.**

[4] Not observing the importance and other reasons.

CHAPTER FIVE

ECONOMETRIC ESTIMATION, REGRESSION RESULTS AND DISCUSSIONS

5.1 Econometric estimation of empirical model parameters

A Stata statistical and econometric package was used to estimate the modified Ricardian model (Model 1 and 2) for Nile basin of Ethiopia (StataCorp, 2003). Econometric analyses with cross-sectional data are associated with problems of outliers, heteroscedasticity, multicollinerity and endogeneity of explanatory variables. Since these econometric issue were likely affect the robustness of the results, the following remedy were taken to its effect

Impact of outliers (unusual and influential data)

The study explored a number of methods of identifying outliers and influential points. In this typical analysis, the study uses only some of the methods. Two types of methods are used for assessing outliers in this study: statistics such as residuals, leverage, Cook's D and DFITS, which assess the overall impact of an observation on the regression results, and statistics such as DFBETA that assess the specific impact of an observation on the regression coefficients. A total of 25 households believed to be outliers for various reasons were omitted.

Heteroscedasticity in the error terms

One of the main assumptions for the ordinary least squares regression is the homogeneity of variance of the residuals. If the model is well-fitted, there should be no pattern to the residuals plotted against the fitted values. Considering this fact, the study tried to see graphical methods such as residual-versus-fitted plot and non-graphical methods such as White's general heteroscedasticity test. Finally, heteroscedasticity in the error terms does not pose a serious

problem for obtaining consistent estimates as it only causes a bias in the estimates of standard errors for which we corrected using White's general method (See Greene, 2003).

Multicollinerity among explanatory variables

Multicollinerity among explanatory variables can lead to imprecise parameter estimates. To explore potential multicollinerity among explanatory variables, the correlation between continuous independent variables were calculated. The result of the correlation analysis indicated that seasonal climate variables were highly correlated since including variables that are nonlinear functions of other variables in the model causes multicollinerity. For example, the independent variables in the model include X and X^2. To solve this problem, it is sometimes suggested that, with such models, the original independent variables should be centered before computing other variables from them. This study, therefore, centers a variable by subtracting the mean from every case. The mean of the centered variable is then zero (the standard deviation, of course, stays the same). The correlations between the independent variables will then often be far smaller. For dummy variables this study used the chi-square tests for independence to determine dependencies between variables. The variance inflation factors (VIF) of all included variables were less than 10, which indicate that multicollinerity is not a serious problem in reduced model. If the sole purpose of regression analysis is prediction or forecasting, then multicollinearity is not a serious problem because the higher the R-squared, the better the prediction (Gujarati, 1995). In general, multicollinearity is a degree and not of kind. The meaningful distinction is not the presence and the absence of multicollinearity, but between its various degrees (Gujarati, 1995). The variance inflation factors for the explanatory variables are presented in Table A-4 and Table A-5 in annex.

Endogeneity of explanatory variables

The problem of endogeneity of explanatory variables can be solved using an instrumental variable (IV) estimator. However, these require valid instrumental variables that are highly correlated with the explanatory variables concerned with but not directly related to revenue. Lacking appropriate instruments makes to resort the next best alternative i.e. estimating a reduced form crop net revenue model rather than a structural model.

Validation of the models

The Fisher-Snedecor test is used 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 6 regressions are all significant at 5% level.

The coefficient of determination (R^2) of the model without adaptation is 14.37%, 18.18%, and 15.57 for the sample that represent Nile basin of Ethiopia, irrigated farms, and dry land farms respectively. Though the integration of adaptation variables improved upon the model (with R^2 =21.77%, 25.54% and 24.27% for the same farm systems mentioned above respectively), a large part of the variation in the agricultural income remains unexplained by the variables taken into account. This is true of farms that vary from small backyard systems to large commercial operations (Kurukulasuriya & Mendelsohn, 2006).

5.2 Results of the regression model

This study explores two main sets of the modified Ricardian model indicated in model one and two. The first includes only climate and soil variables and is referred to as without adaptation model. The second includes relevant socio-economic variables and is referred to as with adaptation model. These additional variables are used to assess the extent to which these additional variables increase or decrease the effect of climate on crops. These socio-economic variables are good policy instruments for policy makers to explore as tools for controlling or taking advantage of climate effects. They are useful to see the importance whether these variables explain crop net revenue. They also control or worsen the adverse impacts of climate change on crops (Benhin, 2006). Within these two broad models the study also investigates whether there are any significant differences in the effects between irrigated and dry land farms. Table 5.1 and 5.2 present the results of these two estimated models.

Table -5.1: Regression results of model without adaptation: climate and soil variables

Independent variables	Full sample	Irrigated	Dry land
Summer temperature	752.55*	1817.14**	915.86**
	(1.75)	(2.42)	(2.39)
Summer temperature sq[5]	-150.66**	204.28**	-185.14**
	(-2.04)	(2.34)	(-2.39)
Winter temperature	470.66	1423.18	-246.67
	(1.28)	(1.41)	(-0.61)
Winter temperature sq	-109.92	45.46	-125.25
	(-1.49)	(1.20)	(-1.56)
Spring temperature	-1580.44***	426.52	-1020.41*
	(-3.34)	(1.49)	(-1.75)
Spring temperature sq	266.10***	258.30	211.45***
	(2.80)	(1.39)	(5.30)
Fall temperature	-688.44***	-4406.21**	-715.78***
	(-4.34)	(-2.34)	(-4.66)
Fall temperature sq	-101.03***	-430.87**	-57.62***
	(-4.76)	(-2.03)	(-3.57)
Summer precipitation	48.51***	39.55*	73.17***
	(3.37)	(1.89)	(3.32)
Summer precipitation sq	0.33***	0.57*	0.39***
	(3.06)	(1.75)	(5.02)
Winter precipitation	228.44***	336.28	387.18**
	(3.81)	(0.02)	(1.99)
Winter precipitation sq	-0.34*	-4.05	-3.54*
	(-1.92)	(-0.36)	(-1.75)
Spring precipitation	-80.62***	-63.67	-112.03***
	(-4.09)	(-0.54)	(-3.27)
Spring precipitation sq	-0.37***	-0.52**	-0.43**
	(-3.25)	(-2.55)	(-2.05)
Fall precipitation	3.24***	-6.17**	-5.07***
	(2.81)	(-2.02)	(-3.43)
Fall precipitation sq	-0.40**	-0.68*	-0.32***
	(-2.43)	(-1.80)	(-3.83)
Sandy soil	*Reference group*		
Clay soil	211.49*	1498.17	-112.02*
	(1.88)	(0.08)	(-1.91)
Dark soil	302.70	540.31*	219.26
	(1.49)	(1.79)	(0.28)
Red soil	328.97	651.86	174.11

[5] Sq is an abbreviation used to represent squared.

	(1.41)	(0.74)	(0.47)
Dark red soil	-142.50*	831.81	-359.08*
	(-1.72)	(0.99)	(-1.70)
Constant	2840.01	1468.09	3580.25
	(0.48)	(0.24)	(1.42)
F	11.44	12.04	10.86
R sq	14.37	18.18	15.57
N	**975**	**179**	**796**

T-Statistics in parenthesis

***Note*: * Significant at 10% level** Significant at 5% level *** Significant at 1% level**

The independent variables in this study include the linear and quadratic temperature and precipitation terms for the four seasons: summer, winter, spring and fall. The effects of the seasonal climate variables vary across the three models in Table 5.1 and 5.2. Both linear and squared terms are significant in certain seasons, implying that climate has a nonlinear effect on crop net revenues. The effect of quadratic seasonal climate variables on crop net revenue is not obviously determined by looking at the coefficients, as both the linear and the squared terms play a role (Kurukulasuriya & Mendelsohn, 2006). Therefore, the climate coefficients will be interpreted based on the marginal effects of climate variables (see section 5.4 for more details).

Table -5.2: Regression results of model with adaptation: climate, soil and socio-economic variables

Independent variables	Full sample	Irrigated	Dry land
Summer temperature	183.34**	-834.80**	295.48***
	(1.97)	(-2.29)	(4.04)
Summer temperature sq	-44.97*	-10.04*	-26.83***
	(-1.69)	(-1.76)	(-4.52)
Winter temperature	-164.75	-93.42	645.05
	(-1.31)	(-1.46)	(0.61)
Winter temperature sq	-86.60	-64.89	-73.54
	(-0.22)	(-0.16)	(-1.57)
Spring temperature	-1138.77**	-691.08	-463.61*
	(-2.02)	(-0.94)	(-1.73)
Spring temperature sq	194.09***	228.38	154.20*
	(5.12)	(0.46)	(1.66)
Fall temperature	474.47**	1062.32*	201.03**
	(2.48)	(1.77)	(2.31)
Fall temperature sq	-154.10***	-10463*	-178.75***
	(-4.8)	(-1.70)	(-4.57)
Summer precipitation	40.51***	0.86**	59.93**
	(4.95)	(2.22)	(2.31)
Summer precipitation sq	0.28***	0.34*	0.33**
	(4.27)	(1.72)	(1.97)
Winter precipitation	149.59***	76.00	284.70*
	(4.68)	(1.00)	(1.94)
Winter precipitation sq	-0.34***	0.30	-3.32***
	(-3.88)	(1.01)	(-3.69)
Spring precipitation	-61.48***	-22.32	-80.24***
	(-3.62)	(-0.05)	(-2.68)
Spring precipitation sq	-0.23*	-0.26*	-0.34*
	(-1.70)	(-1.72)	(-1.66)
Fall precipitation	-2.46*	9.18**	-12.71***
	(-1.75)	(2.52)	(-7.99)
Fall precipitation sq	-0.28*	-0.29**	-0.22**
	(-1.76)	(-2.44)	(-2.25)
Sandy soil	*Reference group*		
Clay soil	423.23	1541.95	69.43
	(1.03)	(1.12)	(0.78)
Dark soil	434.12*	115.13*	346.87*
	(1.89)	(1.77)	(1.89)
Red soil	401.14	192.03	327.37
	(1.03)	(1.12)	(0.78)
Dark red soil	19.85	832.38	-216.43*
	(0.47)	(0.78)	(-1.68)

Irrigation	155.21**		
	(2.35)		
Cropland area	-892.75***	-869.04**	-924.48***
	(-2.70)	(-2.14)	(-7.15)
Livestock ownership	-553.22	-15.92	-746.33
	(-0.81)	(-1.60)	(-0.08)
Distance of input market	-28.99	-61.25	-25.40
	(-0.83)	(-0.32)	(-1.64)
Distance of output market	-11.44*	48.48	-24.32
	(-1.67)	(1.55)	(-0.65)
Access to formal extension	867.52**	740.45	920.97**
	(2.35)	(0.18)	(2.39)
Farm-to-farm extension	458.42	1119.12	464.03
	(0.18)	(0.47)	(1.45)
Access to formal credit	-141.64	-643.38	-517.47
	(-0.68)	(-0.62)	(-0.71)
Log(household size)	258.60*	52.45	324.08
	(1.74)	(0.63)	(1.19)
Years of education of household head	4.58	140.89	25.79
	(1.34)	(1.57)	(1.11)
Farming experience	10.08	41.38	1.82
	(0.20)	(0.55)	(1.43)
Constant	5530.25***	2160.87	6702.15***
	(2.83)	(1.10)	(6.99)
F	7.32	11.66	7.15
R sq	21.77	25.54	24.27
N	**975**	**179**	**796**

T-Statistics in parenthesis

***Note*: * Significant at 10% level ** Significant at 5% level *** Significant at 1% level**

The inclusion of socio-economic variables improved all models in Table 5.2, as indicated by the relative higher R-squared for all models ranging from 7.36% to 8.70%. This indicates that these socio-economic variables are important in explaining crop net revenues.

The regression results in Table 5.2 indicate that irrigation has a positive and significant influence on crop farming in Nile basin of Ethiopia. Irrigation may be one way of adapting to climate change that can be practiced during the dry season and provides farmers with additional income.

Cropland area reduces the value per hectare of farms. Small farms are more productive on a per hectare basis. Small farms may appear to be more productive because they are using fixed resource such as household labor and capital over a smaller piece of land. This is true with the finding that the logarisms of household size is positive in all models but significant in full sample model only. For extensive agriculture farmers increase the area under crops. Though this strategy helps increase the total quantity of produce harvested, it is not efficient because it decreases the yield generally. Most of the time farmers do not have the capacity to manage large areas (Ouedraogo et al., 2006). On the other hand, farmers with larger area may leave it fallow or do not fully utilize. Household size used as proxy for household labor affects revenue positively. This is because for extensive agriculture, the size of the household is vital to supply sufficient labor.

The livestock variable is not statistically significant and the sign and the magnitude is the same for the entire, irrigated and dry land farms.

The distance to input and out market place is negative, as farmers incur more cost in terms of money and time as the market place becomes further from their farm plots. Extensions (public extensions and farm to farm extensions) service helps improve crop net revenue. Access to credit affects crop net revenue negatively. Educational level of the household head used as a proxy for literacy rate and farming experience measured as the number of years respondents have been in farming activities is not significant in any of the models.

The effects of the majority of soils are positive which may be explained by the fertility level and water retention capacity of the soils. However, some of them have negative effect. The

introduction of the soil variables improves the quality of the regressions though many of them are not statistically significant.

In order to interpret the climate coefficients, the marginal effects of the climate variables are estimated using Equation 9 for the model without and with adaptation. Finally, this section concludes by examining the expected climate impacts on crop net revenue using selected uniform climate scenarios for the model with adaptation.

5.3 Marginal impact of climate

The estimated marginal effects of temperature and precipitation on crop net revenues are presented in Table 5.3 and 5.4 on a per hectare basis. These tables show the net annual marginal effect of temperature and precipitation for without and with adaptation models respectively.

The net effects of the seasonal impacts for the model without adaptation indicate that a 1°C increase in annual temperature will lead to a change in crop net revenue of -3358.41 birr for Nile basin of Ethiopia, 3483.25 birr for irrigated farms and -5904.97 birr for dry land farms. All these changes are significant except for irrigated farms. The marginal impacts of precipitation on crop net revenues indicate that an annual increase of 1mm/month of precipitation will have significant positive effects on net revenues. For Nile basin of Ethiopia, an annual net gain of 322.89 birr is expected. A net gain of 309.54 birr and 352.68 birr is expected for irrigated farms and dry land farms respectively.

Table-5.3 Marginal effects of climate variables on crop net revenue based on coefficients in Table 5.1 for model without adaptation

Climate variables	Full sample	Irrigated	Dry land
Temperature	-3358.41*	3483.25	-5904.97***
precipitation	322.89***	309.54**	352.68***

Note: * Significant at 10% level ** Significant at 5% level *** Significant at 1% level

For the model with adaptation, the net effect of a 1°C increase in temperature will decrease crop net revenues by -3127.95 birr and -4485.46 birr for Nile basin of Ethiopia and dry land farms respectively. In both instances the estimates are also significant at 10% and 1% respectively. For irrigated farms, the net effects of the seasonal impacts indicate that a unit increase in annual temperature will lead to an increase in crop net revenue of 2275.41birr. However, the estimate is not significant. The net effect of a 1mm/month increase in precipitation annually will lead to an increase in crop net revenue of 147.45 birr (significant at 5%) for the Nile basin of Ethiopia, 147.46 birr for irrigated farms, and 267.66 birr (significant at 10%) for dry land farms.

Table-5.4 Marginal effects of climate variables on crop net revenue based on coefficients in Table 5.2 for model with adaptation.

Climate variables	Full sample	Irrigated	Dry land
Temperature	-3127.95*	2275.41	-4485.46***
precipitation	147.45**	147.46	267.66*

Note: * Significant at 10% level ** Significant at 5% level *** Significant at 1% level

The policy lesson for adaptation is to take advantage of the positive effects of climate change while reducing the negative ones (Benhin, 2006). Comparing Table 5.3 and Table 5.4, one would therefore expect that including adaptation related variables (socio-economic variables) if they are effective will increase the magnitude of the relationship between climate variables and crop net revenues for positive values while reducing the negative values. This appears to be true for full sample and dry land farms for an increase in temperature. For the full sample, the net effect of a 1°C increase in temperature on crop net revenue has increased from -3358.41 birr to -3127.95 birr, and for dry land farms from -5904.97 birr to -4485.46 birr. For the rest of the results this increase in crop net revenue does not happen either for the increase in temperature or precipitation. What 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. One important variable taken as an adaptation option in the model with adaptation is access to credit, which if not properly undertaken may worsen the problem.

5.4 The impacts of forecasted climate scenarios

The uniform climate scenarios used are based on the projections made by IPCC (2001). According to these projections, the world's average surface temperature should increase by 1.4°C to 5.8°C during the period from 1990 to 2100. In the Sahel, which Ethiopia is part of it, the trend during the past decades shows a reduction in precipitation. For this reason, the necessity for simulating this reduction and an increase in temperature seems to be logical. The simulations for this study were based on scenarios used in the study by Kurukulasuriya and

Mendelsohn (2006) for Africa and Deressa (2006) for Ethiopia. On the basis of this information, this study examined the effect of climatic change for the following scenarios: an increase in temperature by 2.5°C and 5°C and a reduction in the average rainfall by 7% and 14%.

The impact of changing climatic variables on crop net revenue per hectare (NR/ha) for a given district i is given by

$\Delta NR_i = NR_{i,t}(T_t, P_t) - NR_{i,t-1}(T_{t-1}, P_{t-1})$ Where $T_t = T_{t-1} + \Delta T$, $P_t = P_{t-1} + \Delta P$ and $NR_{i,t}(T_t, P_t)$ is the change in crop net revenue per hectare of a given district with temperature and precipitation under the new climate scenarios and $NR_{i,t-1}(T_{t-1}, P_{t-1})$ is the predicted value of crop net revenue per hectare with temperature and precipitation for the base climate scenarios. Hence, the average of ΔNR_i gives the impact of a given climate change scenarios (Deressa, 2006).

Using the coefficients in Table 5.2 and uniform climate changes the results of uniform climate change scenarios are presented in Table 5.5. The results of the above scenarios indicate that an increase in temperature by $2.5^0 C$ will reduce crop net revenue per hectare by 10993.05 birr and 11742.01 birr for Nile basin of Ethiopia and dry land farms respectively. However, a gain of 9661.11 birr will be expected for irrigated farms. A $5^0 C$ increase in temperature will reduce crop net revenue by 12884.57 birr for Nile basin of Ethiopia, 1678.19 birr for irrigated farms and 14550.00 birr for dry land farms. A decrease in precipitation by 7% will reduce crop net revenue by 9918.14 birr, 5383.83 birr and 11235.49 birr for Nile basin of Ethiopia, irrigated farms and dry land farms respectively. A 14% reduction in precipitation will reduce crop net

revenue by 10197.44 birr for Nile basin of Ethiopia, 7763.98 birr for irrigated farms and 14833.63 birr for dry land farms.

Table-5.5: Average crop net revenue per hectare impacts of uniform climate scenarios

Climate change scenarios	**Full sample**	**Irrigated**	**Dry land**
+2. 5^{0}C increase in temperature			
Change crop net revenue (birr/hectare)	-10993.05	9661.11	-11742.01
+5^{0}C increase in temperature			
Change crop net revenue (birr/hectare)	-12884.57	-1678.19	-14550.00
7% reduction in precipitation			
Change crop net revenue (birr/hectare)	-9918.14	-5383.83	-11235.49
14% reduction in precipitation			
Change crop net revenue (birr/hectare)	-10197.44	-7763.98	-14833.63

Note: **Using coefficients in Table 5.2 and uniform climate changes.**

It is obvious that further changes in adverse climate variables i.e. temperature and rainfall are detrimental to crop production. However there is the possibility that adaptation can reduce these negative effects. As indicated in Table 5.5, dry land farms are affected most by further increases in temperature and decreases in rainfall. An increase in temperature and a decrease in precipitation appear to be beneficial for farms with irrigation comparatively, implying that irrigation is important for sustaining agricultural production and as an adaptation option for smallholder farmers. It plays an important role as an additional source of water for crop production, particularly during the dry season and dry spells that can affect agricultural production.

CHAPTER SIX

CONCLUSIONS AND POLICY IMPLICATIONS

This study is an attempt to assess the economic impact of climate change on crop farming activities in Nile basin of Ethiopia, using the Ricardian model.

The results that are obtained from the analysis of marginal impact, uniform climate scenarios and descriptive statistics more or less show the magnitude and direction of climate change impact on crop agriculture. Most of the results of this study show that increasing temperature and decreasing rainfall are damaging to the crop agriculture. In addition to this, the analyses show that dry land farms are most likely affected by climate change. Dry land farms are most likely vulnerable for an increase in temperature and decrease in rainfall than irrigated farms.

Although farmers have some adaptation to climate change, if they continue with their given technology, climate change will have a devastating effect on dry land farms. On the other hand, irrigated farms are more resistant to changes in climate, indicating that irrigation is an important adaptation option for reducing the impacts of changes in climate and used to overcome heat stress.

The results of this study also confirm the importance of climate for crop revenue and the need to take actions to reinforce existing adaptation options and develop new ones. Constraints on adaptation should be removed and better knowledge of climate change promoted. The climate

constraints noted by farmers must be considered as a constant to be used by the concerned bodies, because the economy is strongly influenced by the agricultural sector, which can be affected by climate. The concerned bodies should integrate the strategies actually adopted by farmers to help in the improvement of the sector. There is a need to create more research capacity to develop new crop varieties in the context of changing climatic conditions. The prevailing high percentage of households without adaptation options also testifies the importance of creating a strong system of information and sensitization to help farmers adapt to climatic risks.

Some recommended adaptations are listed below to counteract the harmful impacts of climate change.

- Expansion of new varieties of crops and diversification from traditional crops to other types of crops which can with stand drought and higher temperature;
- There should be a great need for the government through the meteorological department, research and extension, private sector and non-governmental organizations to provide adequate extension information services to ensure that farmers receive up-to-date information about rainfall and temperature patterns in the forthcoming season so that they can make well informed decisions about their planting dates.
- Financing of the rural area by setting up suitable financial systems that will allow small producers to have access to credit. These policies that improve household welfare as well as access to credit are also a priority for both short- and long-term adaptation measures;

- Creating a unit for research into climate, development and societies and strengthening institutional set-ups working in research for large scale dissemination of adaptation technologies by boosting supervision and extension ;
- Expanding good management of water resources that generate more water for irrigation purposes i.e. investment in profitable irrigation technologies.

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ANNEX

Table A-1: Description of the variables used for full sample model

Variables	Mean	St.Dev.
Crop net revenue/ha	2368.67	3850.25
Summer temperature (^0C)	18.25	2.16
Winter temperature (^0C)	18.95	3.25
Spring temperature (^0C)	20.71	2.68
Fall temperature (^0C)	18.16	2.46
Summer precipitation (mm)	269.33	69.00
Winter precipitation (mm)	18.58	11.71
Spring precipitation (mm)	89.75	47.79
Fall precipitation (mm)	102.49	50.28
Clay soil (1/0)	0.18	0.39
Sandy soil (1/0)	0.17	0.34
Dark soil (1/0)	0.59	0.49
Red soil (1/0)	0.61	0.49
Dark red soil (1/0)	0.21	0.42
Irrigation (1/0)	0.18	0.39
Cropland area (ha)	1.72	1.06
Livestock ownership (1/0)	0.92	0.26
Distance of input market (km)	5.61	4.24
Distance of product market (km)	5.67	3.89
Access to formal extension (1/0)	0.55	0.50
Farm to farm extension (1/0)	0.49	0.50
Access to formal credit (1/0)	0.24	0.43
Household size	6.12	2.24
Log (household size)	1.73	0.43
Years of education of household head (years)	1.68	2.74
Farming experience (years)	23.30	12.95

***Source*: EEPFE, EDRI-IFPRI survey data (2004/05) and own calculation.**

Table A-2: Description of the variables used for irrigation model

Variables	Mean	St.Dev.
Crop net revenue/ha	2374.38	4308.83
Summer temperature (^0C)	17.78	1.89
Winter temperature (^0C)	18.71	2.60
Spring temperature (^0C)	20.55	2.29
Fall temperature (^0C)	17.84	1.98
Summer precipitation (mm)	272.75	70.23
Winter precipitation (mm)	17.03	11.44
Spring precipitation (mm)	88.45	51.71
Fall precipitation (mm)	106.65	49.18
Clay soil (1/0)	0.22	0.42
Sandy soil (1/0)	0.16	0.37
Dark soil (1/0)	0.68	0.47
Red soil (1/0)	0.60	0.49
Dark red soil (1/0)	0.44	0.59
Cropland area (ha)	1.94	1.10
Livestock ownership (1/0)	0.95	0.22
Distance of input market (km)	5.83	2.68
Distance of product market (km)	5.90	2.50
Access to formal extension (1/0)	0.69	0.46
Farm to farm extension (1/0)	0.67	0.47
Access to formal credit (1/0)	0.32	0.48
Household size	6.39	2.12
Log (household size)	1.80	0.36
Years of education of household head (years)	2.09	2.93
Farming experience (years)	24.46	13.01

***Source*: EEPFE, EDRI-IFPRI survey data (2004/05) and own calculation.**

Table A-3: Description of the variables used for dry land model

Variables	Mean	St.Dev.
Crop net revenue/ha	2367.39	3742.37
Summer temperature (^0C)	18.35	2.20
Winter temperature (^0C)	19.00	3.37
Spring temperature (^0C)	20.74	2.76
Fall temperature (^0C)	18.24	2.55
Summer precipitation (mm)	268.56	68.74
Winter precipitation (mm)	18.93	11.75
Spring precipitation (mm)	90.04	46.90
Fall precipitation (mm)	101.55	50.50
Clay soil (1/0)	0.18	0.39
Sandy soil (1/0)	0.17	0.38
Dark soil (1/0)	0.57	0.50
Red soil (1/0)	0.61	0.49
Dark red soil (1/0)	0.20	0.43
Cropland area (ha)	1.68	1.04
Livestock ownership (1/0)	0.92	0.27
Distance of input market (km)	5.56	4.51
Distance of product market (km)	5.64	4.14
Access to formal extension (1/0)	0.52	0.50
Farm to farm extension (1/0)	0.44	0.50
Access to formal credit (1/0)	0.22	0.41
Household size	6.06	2.27
Log (household size)	1.72	0.42
Years of education of household head (years)	1.59	2.70
Farming experience (years)	23.04	12.89

***Source*: EEPFE, EDRI-IFPRI survey data (2004/05) and own calculation.**

Table A-4: Variance inflation factor (VIF) test for multicollinearity among variables included in model without adaptation.

Variables	Full sample	Irrigated farms	Dry land farms
Summer temperature	6.58	7.15	8.71
Summer temperature sq	8.75	9.98	4.99
Winter temperature	4.27	7.96	8.25
Winter temperature sq	7.19	5.53	6.91
Spring temperature	8.70	8.41	9.93
Spring temperature sq	4.76	9.30	5.87
Fall temperature	8.02	5.67	8.06
Fall temperature sq	7.99	7.06	8.68
Summer precipitation	1.52	8.87	8.55
Summer precipitation sq	5.79	2.05	8.30
Winter precipitation	7.57	1.43	9.17
Winter precipitation sq	6.07	3.47	5.92
Spring precipitation	9.97	5.95	7.36
Spring precipitation sq	3.84	6.63	5.77
Fall precipitation	6.09	5.55	9.38
Fall precipitation sq	9.71	8.73	9.59
Clay soil	1.44	1.79	1.44
Dark soil	1.43	1.62	1.41
Red soil	1.34	1.47	1.35
Dark red soil	1.06	1.15	1.05
Mean VIF	**5.60**	**5.04**	**6.53**

Table A-5: Variance inflation factor (VIF) test for multicollinearity among variables included in model with adaptation.

Variables	Full sample	Irrigated farms	Dryland farms
Summer temperature	9.49	8.30	5.43
Summer temperature sq	3.55	3.09	7.01
Winter temperature	8.28	5.46	5.28
Winter temperature sq	6.78	7.14	9.04
Spring temperature	3.36	9.17	9.39
Spring temperature sq	4.76	2.42	7.13
Fall temperature	9.33	9.75	9.56
Fall temperature sq	8.03	9.58	8.09
Summer precipitation	3.97	7.57	8.61
Summer precipitation sq	6.60	4.23	9.81
Winter precipitation	8.33	9.94	2.41
Winter precipitation sq	6.50	5.58	6.67
Spring precipitation	9.29	7.82	6.57
Spring precipitation sq	4.27	7.35	6.42
Fall precipitation	6.68	5.52	9.86
Fall precipitation sq	9.94	2.34	9.75
Clay soil	1.46	1.90	1.44
Dark soil	1.44	1.56	1.46
Red soil	1.37	1.83	1.37
Dark red soil	1.08	1.22	1.08
Irrigation	1.18	-	-
Cropland area	1.43	1.60	1.46
Livestock ownership	1.13	1.20	1.15
Distance of input market	2.57	8.03	2.46
Distance of out put market	2.60	7.94	2.52
Access to formal extension	1.88	2.16	1.85
Farm to farm extension	2.12	2.49	2.11
Access to formal credit	1.10	1.20	1.12
Log(household size)	1.18	1.26	1.20
Education	1.29	1.41	1.32
Farming experience	1.27	1.29	1.31
Mean VIF	**4.05**	**4.68**	**4.76**

Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all source of materials used for the thesis have been duly acknowledged.

The examiners' comments have been dully incorporated.

Declared by:

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