

**Economic impact of Climate Change on major South  
African field crops: A Ricardian Approach**

by

**Glwadys Aymone GBETIBOUO**

Submitted in partial fulfilment of the requirements for the degree of

*In memory of my Uncle Michel Bedibeu*

**MSc Agricultural Economics**

in the  
Centre for Environmental Economics and Policy in Africa (CEEPA)  
Department of Agricultural Economics, Extension and Rural  
Development

Faculty of Natural and Agricultural Sciences  
University of Pretoria

PRETORIA, SOUTH AFRICA

July 2004

# Economic Impact of Climate Change on major South African field crops: A Ricardian Approach

By

Ms Gwladys Aymone GBETIBOUO

Degree: MSc

Department: Agricultural Economics, Extension and Rural Development

Supervisor: Prof. Rashid Hassan

**In memory of my Uncle Michel Bedibeu**

## ABSTRACT

*The vulnerability of agriculture to climate change has become an important issue because of reduced crop production, from adverse changes in climate, especially in Africa.*

*This study employed a Ricardian model to measure the impact of climate change on South Africa's field crops and analysed potential future impacts of further changes in the climate. A regression of farm net revenue on climate, soil and other socio-economic variables was conducted to capture farmer-adapted responses to climate variations. The analysis was based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean), climate and edaphic data across 300 districts in South Africa.*

*Results indicate that production of field crops was sensitive to marginal changes in temperature as compared to changes in precipitation. Temperature rise positively affects net revenue whereas the effect of reduction in rainfall is negative. The study also highlights the importance of season and location in dealing with climate change showing that the spatial distribution of climate change impact and consequently*

# **Economic impact of Climate Change on major South African field crops: A Ricardian Approach**

By

**Ms Glwadys Aymone GBETIBOUO**

**Degree: MSc**

**Department:** Agricultural Economics, Extension and Rural Development

**Supervisor:** Prof. Rashid Hassan

## **ABSTRACT**

*The vulnerability of agriculture to climate change has become an important issue because of reduced crop productivity from adverse changes in climate, especially in Africa.*

*This study employed a Ricardian model to measure the impact of climate change on South Africa's field crops and analysed potential future impacts of further changes in the climate. A regression of farm net revenue on climate, soil and other socio-economic variables was conducted to capture farmer-adapted responses to climate variations. The analysis was based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean), climate and edaphic data across 300 districts in South Africa.*

*Results indicate that production of field crops was sensitive to marginal changes in temperature as compared to changes in precipitation. Temperature rise positively affects net revenue whereas the effect of reduction in rainfall is negative. The study also highlights the importance of season and location in dealing with climate change showing that the spatial distribution of climate change impact and consequently*

*needed adaptations will not be uniform across the different agro-ecological regions of South Africa. Results of simulations of climate change scenarios indicate many impacts that would induce (or require) very distinct shifts in farming practices and patterns in different regions. Those include major shifts in crop calendars and growing seasons, switching between crops to the possibility of complete disappearance of some field crops from some regions.*

*I would also like to thank Dr. Ravine Poornath for motivating the present research. I*  
*Keys words: Agriculture, Climate change, sensitivity, net revenue and adaptations.*

*assistance with earlier drafts of the present report.*

*The author wish to acknowledge the financial support of the government of the Republic of Côte d'Ivoire, the Centre for Environmental Economics and Policy in Africa (CEEPA) at the University of Pretoria and her parents Mr. and Mrs. Gbetibouo during the period of her studies. Without the support of all this study could have not been possible.*

*Lastly, I would like to thank my family and friends who gave me encouragement and emotional support in the course of this program. Special thanks to the Abovi family, Mrs. Mampou Mstaie, Mrs. Dalene Duplaxols, Miss Oriko Nazaire, Miss Mapula Johanna, Miss Oyemike Oyenuka, Mr. Patrick Sambayi, Mr. Yemane Gberehwaet, Mr. Letrolao Anthony, Mr. Teddie Nakhumwa and Mr. Patrick Birongi, for making my stay at the University of Pretoria very enjoyable.*

## ACKNOWLEDGEMENTS

This study would not have been accomplished without the participation and support of many people and institutions. Firstly, I would like to thank Prof. Rashid Hassan my supervisor; I was privileged to work with him. His feedback was invaluable in shaping the contents of this study.

I would also like to thank Dr. Ravine Poonyth for motivating the present research. I would also like to express my gratitude to Dr. James Benhin for his valuable assistance with earlier drafts of the present report.

The author wish to acknowledge the financial support of the government of the Republic of Côte d'Ivoire, the Centre for Environmental Economics and Policy in Africa (CEEPA) at the University of Pretoria and her parents Mr. and Mrs. Gbetibouo during the period of her studies. Without the support of all this study could have not been possible.

Lastly, I would like to thank my family and friends who gave me encouragement and emotional support in the course of this program. Special thanks to the Aboui family, Mrs Mampiti Matete, Mrs Dalene Duplessis, Miss Oriko Nazaire, Miss Mapula Johanna, Miss Oyenike Oyenuka, Mr. Patrick Sambayi, Mr. Yemane Gebrehiwet, Mr. Letsolao Anthony, Mr. Teddie Nakhumwa and Mr. Patrick Birungi, for making my stay at the University of Pretoria very enjoyable.

2.3.2 Food supply and food security	13
2.3.3 Agriculture as a source of foreign exchange	16
2.3.4 Agriculture as a source of employment	16
2.3.5 Economic multipliers of South African Agriculture	17
2.4 The field crops' sector	19
2.4.1 Overview of the South African field crops sector	17
2.5.2 Maize	19
2.5.3 Wheat	20
2.5.4 Sugarcane	22
2.5.5 Groundnuts	23
2.5.6 Sorghum	23
2.5.7 Soybeans and Sunflower	24
2.5 Physiological vulnerability to climate change of field crops in South Africa	25
2.5.1 The Agro-ecological features of South Africa	26
2.5.2 Vulnerability of field crops to climate change	29

## TABLE OF CONTENTS

ABSTRACT .....	I
ACKNOWLEDGEMENTS .....	III
TABLE OF CONTENTS .....	IV
LIST OF TABLES .....	VII
LIST OF FIGURES .....	VIII
ABBREVIATIONS .....	X
CHAPTER 1 : INTRODUCTION.....	1
1.1 Background.....	1
1.2 Problem Statement and Motivation.....	3
1.3 Research objectives.....	5
1.4 Approach and methods of the study.....	5
1.5 Outline of the study.....	6
CHAPTER 2 : .....	7
AGRICULTURE AND THE CLIMATE IN SOUTH AFRICA.....	7
2.1 Introduction.....	7
2.2 Land use, Climate and the Natural resources of South Africa.....	7
2.3 The importance of agriculture to the South African economy .....	12
2.3.1 Contribution to GDP .....	12
2.3.2 Food supply and food security .....	13
2.3.3 Agriculture as a source of foreign exchange .....	16
2.3.4 Agriculture as a source of employment.....	16
2.3.5 Economic multipliers of South African Agriculture .....	17
2.4 The field crops' sector.....	19
2.4.1 Overview of the South African field crops sector.....	19
2.5.2 Maize .....	19
2.5.3 Wheat .....	20
2.5.4 Sugarcane.....	22
2.5.5 Groundnuts.....	23
2.5.6 Sorghum.....	23
2.5.7 Soybeans and Sunflower.....	23
2.5 Physiological vulnerability to climate change of field crops in South Africa.....	26
2.5.1 The Agro-ecological features of South Africa.....	26
2.5.2 Vulnerability of field crops to climate change .....	29

<b>CHAPTER 3 : LITERATURE REVIEW ON CLIMATE CHANGE AND AGRICULTURE.....</b>	<b>31</b>
3.1 Introduction.....	31
3.2 The Process of climate change.....	31
3.3 Climate change effects on agricultural productivity .....	33
3.4 Economic and social impacts of climate change on agriculture .....	34
3.5 The distribution of climate change impacts .....	36
3.6 Policy implications of climate change: Mitigation and Adaptation .....	37
<b>3.7. Measurement of climate change impacts on the agricultural sector.....</b>	<b>40</b>
3.7.1 Structural modelling of the Agronomic Response.....	41
3.7.1.1 Agronomic-economic models (AEM) .....	41
3.7.1.2 Agro- Ecological Zones models.....	44
3.7.2 Observed Response Models: Cross sectional methods .....	45
3.7.2.1. The Ricardian Approach.....	45
3.7.2.2 The Future Agricultural Resources Model: FARM.....	47
<b>3.8 Empirical studies of climate change impacts on agriculture.....</b>	<b>48</b>
3.8.1 Climate change impacts literature in developed countries .....	48
3.8.2 Studies on climate change impacts on Agriculture in developing countries .....	50
3.8.3 Studies on climate change impacts on Agriculture in South Africa.....	52
<b>CHAPTER 4 : THE RICARDIAN APPROACH AND EMPIRICAL MODEL OF CLIMATE CHANGE IMPACTS ON FIELD CROPS IN SOUTH AFRICA .....</b>	<b>56</b>
4.1 Introduction.....	56
4.2 The Ricardian approach.....	56
4.2.1 Theoretical background .....	56
4.2.2 The analytical model .....	57
4.4 Specification of the empirical model .....	59
4.4.1 The field crops' climate response model.....	59
4.4.2 Regressors of the model.....	60
4.4.3 Sources of the data .....	62
<b>CHAPTER 5 : RESULTS OF THE EMPIRICAL ANALYSIS .....</b>	<b>70</b>
5.1 Introduction.....	70
5.2 Parameters' estimation procedures.....	70
5.3 Results of the regression analysis.....	72
<b>5.4 Climate sensitivity of the South African field crops.....</b>	<b>75</b>
5.4.1 Elasticity measures.....	75
5.4.2 Climatic optimum points.....	76
5.4.2.1 Identification of climatic optimum points .....	77
5.4.2.2 The sensitivity of climatic optimum points to other climate attributes.....	81
<b>5.5 Likely impacts of climate change on the South African Field Crops .....</b>	<b>85</b>
5.5.1 Simulation procedures .....	85
5.5.2 Climate change impacts results.....	88

5.5.2.1 Partial effects analysis.....	88
5.4.2.2 Seasonal effects analysis.....	89
5.4.2.3 Total effects.....	92
5.4.2.4 Distributional effects.....	93
<b>CHAPTER 6 : CONCLUSIONS AND IMPLICATIONS OF THE STUDY .....</b>	<b>99</b>
6.1 Findings of the study.....	99
6.2 Limitations and Future studies .....	101
6.3 Conclusions and policy implications .....	102
<b>REFERENCES.....</b>	<b>104</b>
Table 5-1: Parameter estimation of the Ricardian field crops model .....	72
Table 5-2: Estimates of elasticity to climate factors .....	76
Table 5-3: Current level, critical point and agronomic optimal temperatures .....	78
Table 5-4: Current level, critical damage point and agronomic optimal level of temperature .....	80
Table 5-5: Simulation scenarios .....	87
Table 5-6: Current level of provincial rainfall and temperature .....	87
Table 6-1: Impacts of changing only temperature or rainfall on field crops' net revenue in percentage (%).....	100
Table 6-2: Sensitivity of the impacts of climate change on net revenue to climate scenarios in percentage (%).....	101



## LIST OF TABLES

Table 2-1: Average production and consumption and Self-Sufficiency Indices (SSI) of selected agricultural commodities in South Africa (1995- 2000) .....	14
Table 2-2: Expected requirements of basic agricultural products in South Africa by the years 2010 and 2020.....	14
Table 2-3: Trends in South Africa's agricultural exports (1980-2000).....	16
Table 2-4: Optimal climatic conditions for growth of field crops .....	30
Table 4-1: Definition of the variables included in the empirical analysis .....	61
Table 5-1: Parameter estimation of the Ricardian field crops model .....	73
Table 5-2: Estimates of elasticity to climate factors .....	76
Table 5-3: Current level, critical point and agronomic optimal temperatures .....	78
Table 5-4: Current level, critical damage point and agronomic optimal level of precipitation.....	80
Table 5-5: Simulations scenarios .....	86
Table 5-6: Current level of provincial rainfall and temperature .....	97
Table 6-1: Impacts of changing only temperature or rainfall on field crops' net revenue in percentage (%).....	100
Table 6-2: Sensitivity of the impacts of climate change on net revenue to climate scenarios in percentage (%).....	101
Figure 3-15: The main cropping zones of the field crops .....	28
Figure 4-1: Net revenue Hectare in South Africa by district (1993) .....	65
Figure 4-2: Average Summer Temperature in South Africa by district (1970- 2000) .....	66
Figure 4-3: Average Winter Temperature in South Africa by district (1970 - 2000) .....	67
Figure 4-4: Summer Rainfall in South Africa by district (1970 -2000).....	68
Figure 4-5: Winter Rainfall in South Africa by district (1970 - 2000).....	69
Figure 5-1: The sensitivity of net revenue to winter temperature .....	78
Figure 5-2: The sensitivity of net revenue to summer temperature .....	78
Figure 5-3: The sensitivity of net revenue to winter rainfall .....	80
Figure 5-4: The sensitivity of net revenue to summer rainfall .....	80
Figure 5-5: Variation of temperature critical points to rainfall in summer.....	82
Figure 5-6: Variation of temperature critical points to rainfall in winter .....	82
Figure 5-7: Variation of Rainfall critical points to temperature levels in summer.....	84
Figure 5-8: Variation of Rainfall critical points to temperature levels in winter.....	84

## LIST OF FIGURES

Figure 2-1: South African Mean Annual Precipitation (1960-1990).....	9
Figure 2-2: South Africa Meteorological Profile.....	9
Figure 2-3: South Africa vegetation- biome .....	11
Figure 2-4: Contribution of the South African Agriculture to Gross Domestic Product (1965-2000).....	13
Figure 2-5: Trend of Producer prices of agricultural products at 1995 prices (1965- 2000).....	15
Figure 2-6: Value of transactions of the Agro-food complex in 2000 (R millions) ....	18
Figure 2-7: The trend in maize production and area planted (1975-2000).....	21
Figure 2-8: The trend in wheat productions and area planted (1975-2000) .....	21
Figure 2-9: The trend in sugarcane production and area planted (1975- 2000).....	22
Figure 2-10: The trend in groundnut production and area planted (1975- 2000) .....	24
Figure 2-11: The trend in sorghum production and area planted (1975-2000).....	24
Figure 2-12: The trend in soybean production and area planted (1975- 2000).....	25
Figure 2-13: The trend in sunflower production and area planted (1975-2000).....	25
Figure 2-14: The Agro-climatic zones in South Africa .....	28
Figure 2-15: The main cropping zones of the field crops .....	28
Figure 4-1: Net revenue Hectare in South Africa by district (1993) .....	65
Figure 4-2: Average Summer Temperature in South Africa by district (1970- 2000)	66
Figure 4-3: Average Winter Temperature in South Africa by district (1970 – 2000) .	67
Figure 4-4: Summer Rainfall in South Africa by district (1970 –2000).....	68
Figure 4-5: Winter Rainfall in South Africa by district (1970 – 2000) .....	69
Figure 5-1: The sensitivity of net revenue to winter temperature.....	78
Figure 5-2: The sensitivity of net revenue to summer temperature .....	78
Figure 5-3: The sensitivity of net revenue to winter rainfall .....	80
Figure 5-4: The sensitivity of net revenue to summer rainfall.....	80
Figure 5-5: Variation of temperature critical points to rainfall in summer.....	82
Figure 5-6: Variation of temperature critical points to rainfall in winter .....	82
Figure 5-7: Variation of Rainfall critical points to temperature levels in summer .....	84
Figure 5-8: Variation of Rainfall critical points to temperature levels in winter.....	84

Figure 5-9: The partial effects of a 2 <sup>0</sup> C increase in temperature and 5% reduction in precipitation on net revenue .....	89
Figure 5-10: Impact of a 2 <sup>0</sup> C increase in winter and summer temperature on net revenue .....	90
Figure 5-11: Impact of 5% decrease in winter and summer precipitation on net revenue .....	91
Figure 5-12: Cumulative seasonal impacts of a 2 <sup>0</sup> C increase in temperature and a 5% decrease in rainfall for summer and winter .....	91
Figure 5-13: The sensitivity of climate change impacts on net revenue across different climate change scenarios .....	93
Figure 5-14: Distributional effects of 2 <sup>0</sup> C increase in temperature across South African provinces .....	94
Figure 5-15: Distributional effects of 5% reduction in rainfall across South African provinces .....	95
Figure 5-16: South Africa provinces delimitation .....	97
Figure 5-17: Distributional effects of 2 <sup>0</sup> C increase in temperature and 5% reduction in rainfall across South African provinces .....	98

- NOAA National Oceanic and Atmospheric Administration
- NWDSA National Weather Bureau of South Africa
- O<sub>3</sub> Ozone
- ppm Parts per million
- SAM Social Accounting Matrix
- SAAGIS South Africa Agricultural Geo-referenced Information System
- t Ton
- UNFCCC United Nations Framework Convention on Climate Change
- USA United States of America

## CHAPTER 2 ABBREVIATIONS

<b>AEM</b>	Agronomic-Economic Models
<b>AEZ</b>	Agro-Ecological Zones
<b>AGE</b>	Applied General Equilibrium
<b>ARC</b>	Agricultural Research Council
<b>°C</b>	Degree Celsius
<b>CH<sub>4</sub></b>	Methane
<b>CO<sub>2</sub></b>	Carbon dioxide
<b>FAO</b>	Food and Agriculture Organisation
<b>GCMs</b>	Global Circulation Models
<b>GDP</b>	Gross Domestic Product
<b>CGE</b>	Computable General Equilibrium
<b>GHG</b>	Greenhouse gases
<b>GIS</b>	Geographical Information Systems
<b>ha</b>	Hectares
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>ISCW</b>	The Institute for Soil, Climate & Water
<b>LUT</b>	Land Utilization Types
<b>m<sup>3</sup></b>	Cubic meters
<b>mm</b>	Millimetres
<b>N<sub>2</sub>O</b>	Nitrous oxide
<b>NOAA</b>	National Oceanic and Atmospheric Administration
<b>NWBSA</b>	National Weather Bureau of South Africa
<b>O<sub>3</sub></b>	Ozone
<b>ppm</b>	Parts per million
<b>SAM</b>	Social Accounting Matrix
<b>SAAGIS</b>	South Africa Agricultural Geo-referenced Information System
<b>t</b>	Ton
<b>UNFCC</b>	United Nations Framework Convention on Climate Change
<b>USA</b>	United States of America

<sup>1</sup> ppm (parts per million) and ppb (parts per billion) measure the ratio of the number of greenhouse gas molecules to its total number of molecules of dry air in million and billion units, respectively.

<sup>2</sup> This was the most sceptical scenario before the new estimates of IPCC (2001), which reported a range between 1.4 to 5.8 °C over the period 1990 to 2100.